Redesign of a Finger Vein Scanner

Bachelor Thesis

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***Abstract*—Finger vein recognition is emerging as a new form of biometrics. There are multiple devices that are commercially available which claim to have an outstanding performance. However, little research is done into finger vein scanners. The SCS group designed their own finger vein reader, but it needed a redesign. This paper focuses on the important aspects for a redesign like: camera, IR pass filter and illumination method. Also a method is proposed that evaluates the image quality of a vascular pattern image. This is done by looking at the contrast between finger tissue and vein, the homogeneity of the image and the overexposure of the finger contours. The evaluation method is used to compare the performance of the old setup with the new setup. In this comparison the new device performed better, but there are many aspects that still need to be investigated before such statements can be made.**

***Index Terms*—Vascular pattern, Finger vein, Biometric, Near Infrared(NIR).**

I. Introduction

Fingerprint recognition is used in many applications nowadays. Think of, for example, to access content on a mobile phone or laptop. It is an easy way to identify a person, but there are various methods to fool a fingerprint sensor. Therefore, in 2012 the SCS Group has done research into another solution. This solution creates an image of the vascular pattern in a finger. This solution is already used in the industry however, there is little academic research done in this field. The goal of the previous research was to get a better understanding of this new form of biometrics and to design a device that is capable of capturing images of the vascular pattern.

The finger vein scanner that has been designed in the SCS Group is large and bulky. Therefore, it is inconvenient to carry the device. Hence, a redesign is required. Important factors for the redesign are the choice for a near infrared camera, the placement of the near infrared LEDs and filtering of visible light.

The goal of this bachelor assignment is to create a new device that is smaller than the existing setup while maintaining or even improving the image quality of the vascular pattern images. Therefore, also a method has to be found to evaluate the image quality of vascular pattern images.

In section II illumination types are discussd and this section shows devices that are commercially available and devices from research. Then in section IIIaspects are mentioned that determine the image quality of a vasclar pattern image and an evaluation method is proposed. After that, in section IV, requirements are given for the device that is to be designed. Then, in section V an overview is given of the system that has been designed. Then in section VI it is described how each of the system components is implemented in the new device. The evaluation of the device is done in section VII and at the end of this paper several conclusions and recommendations for future work are given.

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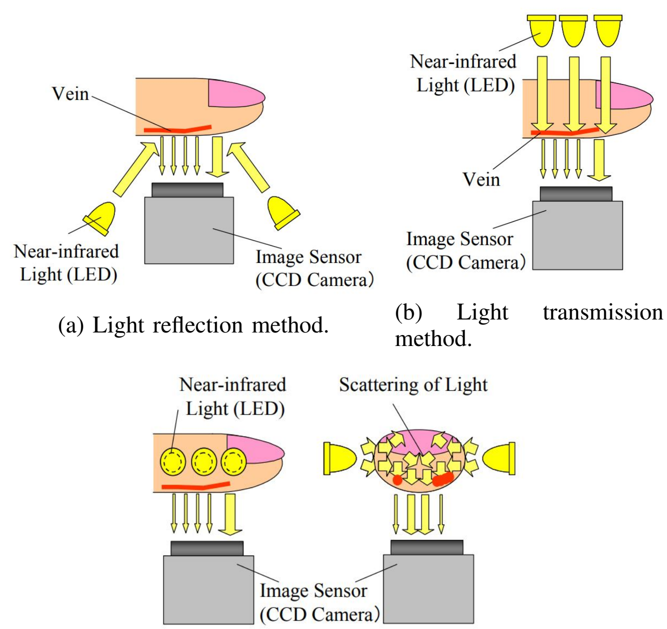
II. State of the art techniques and devices

Devices that capture the vascular pattern inside a finger are based on the fact that the hemoglobin inside the veins has a higher absorbency of Near InfraRed Light(NIR light) than the surrounding tissue. This means that the vascular pattern inside a finger can be captured by a device that is sensitive to NIR light. There are already some devices on the market that are capable of capturing the vascular pattern. Also, some academic research is done into this fairly new bio-metric. This research goes along with the creation of custom made devices. But first the different types of illumination in these devices need to be discussed.

A. Types of Illumination

The veins have to be made visible with NIR light, but there are multiple possibilities to place the LEDs around the finger. The main types that are found in existing devices are shown in figure 1.



(a) Light reflection method.

(b) Light transmission method.

(c) Side Lighting method.

Fig. 1: Illumination types [1]

The illumination with the **light reflection method** is at the same side as the camera. This allows for the device to be more compact. During operation the user of the device can still see his finger. The disadvantage of this method is that the image sensor mainly captures the reflected light from the surface of the finger, because the light shallowly penetrates the skin. Hence, this method gives images with low contrast between tissue and veins.

The **light transmission method** does deliver high contrast vascular pattern images, because the light passes through the finger and no reflections of the surface are captured. The illumination is at the other side of the finger relative to the camera. The disadvantage of this method is that the user has to put his finger into the device such that he can't see his finger anymore. This can cause discomfort for some users.

The third illumination type is **side lighting method**. This method still allows an open device such that the user can see his finger. The light sources are placed on either one side or both sides of the finger. NIR light goes through the sides of the finger and scatters there, before it is captured by the image sensor. This method does allow for high contrast images. However, the sides of the finger are overexposed in the images.

B. *Devices in industry*

The market leader in finger vein capturing devices is Hitachi. They have developed multiple systems that are capable of capturing finger vein images. The technology is even used in atm machines in Poland [2].

Figure 2 shows the Hitachi H1, a USB finger vein authentication device. The user has to put his finger in the device. This means that the users view on their finger is obstructed. Hitachi claims that it has a FRR of 0.01% and a FAR of 0.0001% [3]. This device usess the light transmission lighting method.

Fig. 2: Hitachi H1 finger vein scanner. [Model: PC-KCA110] [3]

Figure 3 shows another device from Hitachi which uses a different type of illumination. The finger is illuminated from the sides. The user of this device can still see his finger when the vascular pattern is captured.

The smallest device Hitachi developed is only 3mm thick [5]. It makes use of a contact image sensor. Each pixel of the CMOS sensor has a micro lens. The distance between the pixels is 0.1mm. The total pixel count of the device is 150x100. The illumination method of this device is slightly different than the light reflection method. The lighting still

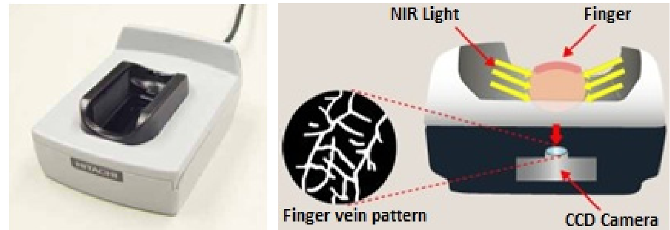


Fig. 3: Hitachi finger vein reader. [TS-E3F1-602UE] [4]

comes from below, but there is light blocking material between the camera area and the NIR light source. This means that there is no reflection. The light has to enter the finger first then scatter inside the finger before it is captured by the contact image sensor. See figure 4

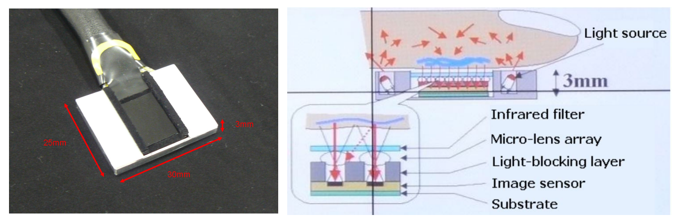


Fig. 4: Hitachi's 3mm-thick finger vein authentication module

Another company that builds finger vein capturing devices is Mofiria. A daughter company of Sony. This company also has multiple devices and even delivers development kits. They claim that it has a FRR of 0.1% and a FAR of 0.0001% [6]. Figure 5 shows one of the devices. It also is a USB finger vein scanner. The user can see his finger when the vascular pattern is captured. The IR-light comes diagonally from above. Therefore, the device still the light transmission method.

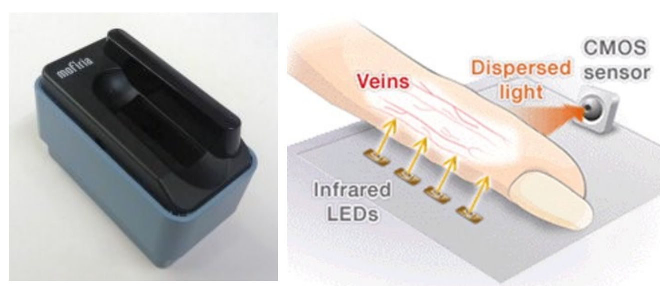


Fig. 5: Mofiria finger vein scanner. [Model: FVA-U4ST]

Mofiria also has a smaller device which is even easier to carry around. It uses the same operating principle as the device in figure 5, but the concept is rotated. You now have to put your finger on its side on the device. The IR light enters the side of the finger and scatters. The CMOS camera is put next to the finger to capture the vascular pattern from below. The device can be seen in figure 6.

Fig. 6: Mofiria finger vein scanner. [Model: FVA-U3SX]

C. Devices in research

Researchers mainly build their own finger vein scanner and then develop software to subtract the veins from the acquired images. One aspect stands out in the devices researchers have built. They all use the light transmission method.

In the lab for Advanced Signal Processing of the Civil Aviation University of China they have built a finger vein scanner. The main IR LEDs are positioned above the finger and the camera is placed below the finger. There are also additional LEDs below the finger. It is said that this improves the contrast between the veins and finger tissue. The device capture the vascular pattern when the position sensor is triggered. The top of the finger should trigger the position sensor. The device can be seen in figure 7

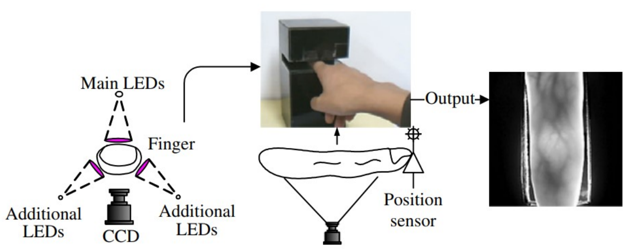


Fig. 7: Finger vein scanner of Aviation University of China [AUC] [7].

The University of Electronic Science and Technology of China built the device in figure 8. It is a finger vein scanner that has 3D capabilities as well. They placed the cameras above the finger and the illumination below the finger. Both of the cameras are placed along the length of the finger. The reason for this is that both of the cameras are behind the finger and never have IR light directly in the camera.

The SCS group also made their own finger vein scanner (see figure 9). The setup makes use of the light transmission method, but the camera isn't directly positioned underneath the IR LEDs. The camera is big and it would have given the setup a substantial height if it would be under the IR LEDs. Hence, a mirror is positioned under the IR LEDs such that the camera is horizontally fitted in the box. The camera that is used is a BCi5 monochrome CMOS camera. It has a firewire interface and is produced by C-Cam technologies. The camera has a Pentax H1214-M machine vision lens fitted with a focal length of 12 mm. On top of that is a B=W 093 IR filter. The IR

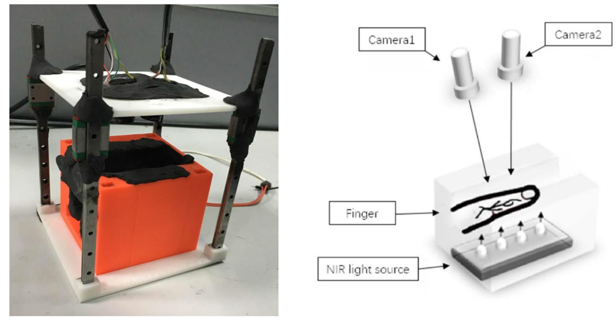


Fig. 8: 3D finger vein scanner of the University of Electronic Science and Technology of China [UESTC-3D] [8].

LEDs are the SFH4550. These LEDs have a small half angle of 3° and a radiant intensity of typically 700 mW/sr. This is more than enough to trans illuminate the thickest fingers. They are controlled by a custom made LED controller. This controller can be used within the matlab environement. Matlab is also used for the processing of all the captured images.

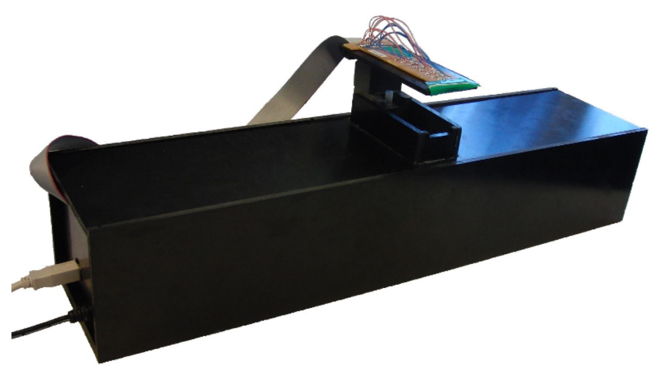


Fig. 9: Finger vein scanner of the SCS group of the University of Twente [SCS-Group] [9].

In table I and overview of all the mentioned devices can be seen together with the illumination method and camera position.

Device	Illumination method	Camera Position
PC-KCA110	Light Transmission	Below Finger
TS-E3F1-602UE	Side Lighting	Below Finger
Hitachi 3mm	Light Reflection	Below Finger
FVA-U4ST	Light Transmission	Below Finger
FVA-U3SX	Light Transmission	Below Finger
AUC	Light Transmission	Below Finger
UESTC-3D	Light Transmission	Above Finger
SCS-Group	Light Transmission	Below Finger

TABLE I: Overview of devices in industry and research.

III. Image quality assessment

One of the most important factors for the redesign is the image quality. This must be as good as it was in the old setup or even be improved. But, how can this be tested? In literature, there is not much said about the image that is taken by a finger vein scanner. Only whole systems are tested. This includes all the operations that are done on the image and in most cases it gives the score for how well it can match images(EER or FAR). But this does not say anything about how good the images itself are. The following aspects are considered in order to compare the new setups image quality with the image quality of the old setup.

A. Contrast

The contrast between a finger vein and finger tissue says something about the image quality. Namely, the larger the difference in grey values, the better the contrast between the two. This is important because with a better contrast between vein and tissue it becomes easier to find the veins in the image. In order to do so, two areas are taken from a vascular pattern image. One area with vein and one without vein (only tissue). Of each area, the average grey value is calculated and compared.

B. Uniformity of illumination

The uniformity of the illumination along the finger is also important for the image quality. The tissue of the finger should have similar brightness(grey value) along the finger. If certain parts of the finger have a higher or lower brightness then the contrast between vein and tissue gets lower. An optimal grey value for finger tissue is taken from the old setup. This value is 80 [10]. The old setup also had hardware that could change the light intensity of each light source. Hence, this should also be possible with the new setup.

C. Overexposure of finger contours

The veins are hardly visible on the sides of the finger if they are overexposed. This is possible if the side lighting method is used or if the light reflection method is used. It can also happen with the light transmission method, but that mainly means that illumination brightness is too high. However, it is very hard to attach numbers to this aspect. Hence, this will be compared subjectively.

D. Format

One aspect that defines images is the image resolution. A higher resolution means that more detail can be seen (more pixels per cm^2) in the images, but it also means that more processing time is needed in order to do similar mathematical operations. Hence, a trade off has to be made between resolution and processing time. The old setup made images with a resolution of 672x380.

E. The proposed evaluation method

Above there are some aspects mentioned that can indicate whether or not a finger vein image is of good quality, but how can the image quality be evaluated? And how can it be verified that the new device is better than the old one? There are many parameters that influence the image quality. Like the position of the finger in the device, the light from external sources, the control settings for the IR LEDs, warm or cold hands. A soap model with some ’veins’ will be used in order to reduce the influence of human factors.

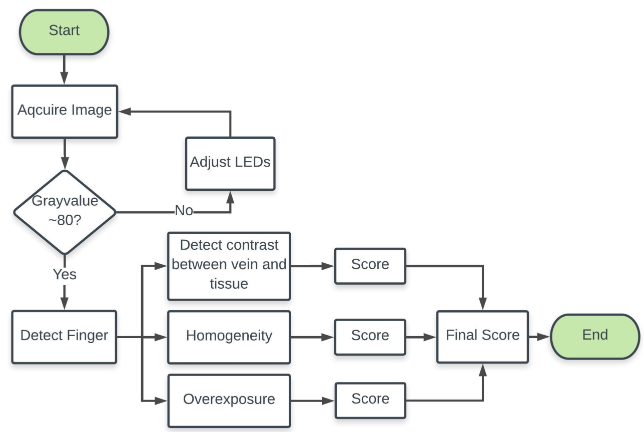


Fig. 10: The system flow diagram of the proposed image quality assessment

In figure 10 a flow diagram is given of the proposed evaluation method. First, an image is captured by the camera. Then the average grey value for a region of 40 x40 pixels under each LED is calculated. If each region has an average grey value close to 80 then the Detect Finger algorithm is applied. This algorithm detects the edges of the finger and deletes the background from the image.

For the Homogeneity the Gray-Level-Co-occurrence Matrix(GLCM) can be used.

> ”The GLCM functions characterize the texture of an image by calculating how often pairs of pixel with specific values and in a specified spatial relationship occur in an image, creating a GLCM, and then extracting statistical measures from this matrix.”,
> -Mathworks [11]

One of the statistical measures that can be extracted from the GLCM is homogeneity. The formula is given in equation 1. It measures the closeness of the distribution of elements. This formula will be used to calculate the homogeneity of the finger vein image. The formula returns a value between ’0’ and ’1’. A ’1’ means that the picture only has 1 grey level.

$$\sum_{i,j} \frac{p(i,j)}{1+|i-j|} \tag{1}$$

The contrast of an image can also be calculated by the GLCM. The formula is given in 2. It is a measure of the intensity contrast between a pixel and its neighbor pixel over the whole image. The range = [0 (size(GLCM-1)^2]. If the contrast is 0 then the image is constant.

$$\sum_{i,j} |i-j|^2 p(i,j) \tag{2}$$

The overexposure of the finger contours is compared subjectively. The contours of the finger should have the same brightness as the mid of the finger. Otherwise, the veins close to the contours will not be visible anymore due to overexposure. Therefore, if the finger is equally bright everywhere the resulting score is high and if the contours are overexposed the resulting score is low.

IV. Design criteria

The device that is to be designed has to meet some requirements. These requirements follow from the objective of this assignment, but there are also requirements that follow from future research that is to be done within the SCS group. These requirements are stated below.

A. Compactness

The old design of the finger vein scanner is quite large. The new design should have a smaller form factor such that it will be easier to carry the device. However, there are certain dimensions that cannot change. The viewing area of 56 x 33 mm (L x W) is found to be optimal in the old setup as these dimensions depend on the average length and width of a human finger. One of the main factors that dictates the form factor is the camera. Since, the camera should be small and focus on an object that is close to the camera. The camera should be able to take pictures of the whole viewing area of 56x33 mm(LxW). So, preferably it should be a camera with a large viewing angle. The other main factor is the computer, since the computer needs its space as well. It also should be easy to connect peripherals like a camera and LEDs to the device.

B. Image quality

One of the most important factors for the redesign is image quality. The new device has to maintain or even improve the image quality of the captured vascular pattern images. This is more extensively explained in section III. The image quality will also be assessed.

C. Usability for research

In the SCS group research is done into finger vein scanners and images. From this research some would like to investigate how the light scatters inside the finger if the illumination comes from different angles. Others would like to see whether or not it is possible to make 3D reconstructions of the vascular pattern. Therefor, the new setup will also be an experimental setup in which things like the amount of cameras and illumination can be changed. The illumination will be similar to the old setup when it comes to the amount of LEDs in an LED array and the way in which they are controlled. The old setup has 8 in an array in order to cover the whole finger. The LEDs can be controlled separately when it comes to the amount of current going through it. This is important because the thickness along the finger varies. Thus the thicker parts require a higher intensity of IR-light in order to make the veins visible.

V. System overview

The criteria that are given in the previous section result in a selection of components for the new device. In figure 11 an overview is given of the whole system.

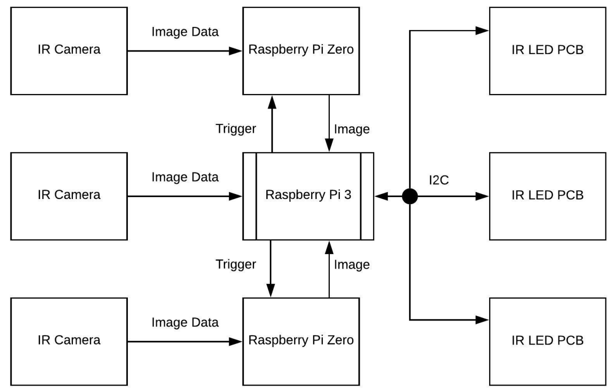


Fig. 11: Overview of the system in the finger vein scanner.

A. Computer

The selection for the computer is influenced by the compactness criteria. There are multiple credit card sized computers available, but the one that is used most is the Raspberry Pi. The Raspberry Pi 3 has enough computing power to do the necessary image processing. It is also quite easy to connect peripherals to the device, because the device has a CSI connector for a camera and 40 GPIO pins and 4 USB ports. However, only one camera can be connected to the CSI connector and using a USB port is not an option as this uses to much bandwidth on the USB bus. It also takes a lot more processing power than the CSI interface. So, two more computers are added to the design. These computers are Raspberry Pi Zeros. They are even smaller than a Raspberry Pi 3, but have significantly less computing power. Therefore, they will only be used to capture images and send them to the Raspberry Pi 3 for processing.

B. Camera's

There are multiple camera's available that can be connected to the CSI connector of the Raspberry Pi. So, a camera has to be chosen that is small and can capture images at a close distance. Hence, a camera with a wide angle lens. The camera that is chosen is a 5 Mega Pixel RB-Camera-WW from Joy It. It has an optical Field Of View of 120° horizontally. Which is the largest FOV that was available. This has also a downside, namely the image is distorted(straight lines appear to be rounded). However, this can be solved by correcting for the lens distortion within the software.

The camera comes fitted with an IR filter, but this can be removed. The only problem then is that the camera is still sensitive to visible light. This problem is resolved by using an IR pass filter. It can be fitted inside the camera or it can be placed in front of the camera.

C. Infrared light

There are no pre made high power IR LED strips available. The old setup had 8 high power IR LEDs with a half angle of 3°. The radiant intensity is typically 700 mW/sr. Hence, the IR lighting needs to be custom made. It is important that a LED driver chip is used that has a constant current source. Otherwise flickering (changes in intensity) might be noticed when the images are captured. The LED driver should be capable to alter the intensity of each LED separately, because the intensity of each LED is indirectly determined by the thickness of the finger. Most LED drivers use Pulse Width Modulation(PWM) to adjust the intensity. The frequency of the PWM should be much higher then the rolling shutter speed of the camera. Otherwise images are captured which are very bright on one side(the IR LED is on) and very dark on the other side(the IR LED is off).

The IR LED strip should be compact as well. Therefore, a custom Printed Circuit Board(PCB) is designed that houses the IR LEDs and LED driver. The amount of wires connected to this PCB should be kept to a minimum. Otherwise, the device will look like a cable mess.

D. Infrared pass filter

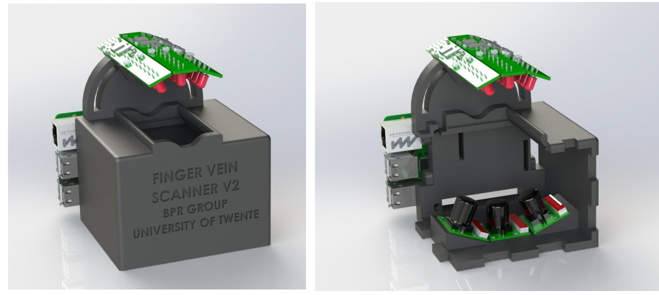
The old setup uses an IR pass filter in order to filter the visible light. Having visible light in the vascular pattern images makes it harder to find the vascular pattern. Hence, the new setup needs to have an IR pass filter as well.

VI. Implementation

The Pi's, camera's and IR_LED_PCB need to be fitted and kept in place as well. Hence, a housing needs to be designed. If adjustments need to be made for some research project then it should be easy to modify parts. Therefor it is chosen to make a 3D model of the housing and 3D print all the parts. The user can alter a part, 3D print it and within a couple of hours use it already. 3D printing is also cheap and there is almost no loss in materials.

The 3D model can be seen in figure 12. The camera's are fixed in the model and cannot move. They are all focused on the center of a finger. The IR_LED_PCBs can move around the arc by loosening a screw at the backside of the device. Or they can be taken off. The IR pass filter is just a couple of millimeters below the finger. It also closes the box. This IR pass filter can not be seen in the 3D model. The Raspberry Pi 3 is placed behind the box and the Pi Zeros are placed on both sides in the box (not in the model).

A close up of the top of the IR_LED_PCB can be found in figure 13. On this PCB there is a LED driver capable of driving each of the LEDs with a current of 100mA. The LED driver is controlled by an ATMEGA328P-AUR mirco-controller. The micro-controller can be programmed through the ICSP header(Header P2). Or if the Arduino boot loader is already on the micro-controller, then the chip can also be programmed with a USB-TTL serial adapter (Use header P3). The Raspberry Pi 3 can communicate with the micro-controller via a I2C bus.



(a) 3D model. (b) Insde of the 3D model.

Fig. 12: 3D model of the finger vein scanner.

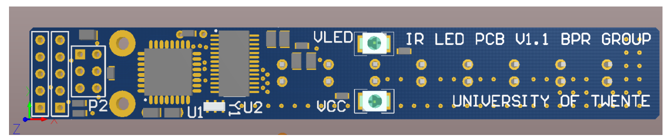


Fig. 13: The design for the IR_LED_PCB

The device is powered by a 12V 3A adapter that is connected to the grid. A 5V supply and a 3.3V supply is made from this 12 Volts. The 5V is used to power the Raspberry Pi 3 and the other IC's. The 3.3V is used to power all the IR LEDs. The Raspberry Pi 3 is attached to a PC with an ethernet cable. The SD card contains a Matlabserver that is installed by the Raspberry PI hardware support add on. This Matlabserver can be accessed from within the Matlba environement.

VII. Evaluation

The actual device can be seen in figure 14. However, due to time limitations the system only works with the camera in the middle. Also, only one IR_LED_PCB has been made and is operating. The new setup operates similar to the old setup. It only is much smaller than the old setup.

The IR_LED_PCB can be moved around the arc. Hence, research can be done into how the light scatters inside the finger. If the device is also capable of using the other two cameras then it can be investigated if 3D finger vein reconstructions can be made.

A. Image Quality Evaluation.

Figure 15 shows images that are taken with the old setup. Figures 15a and 15b are 'vein images' of a soap model. Figure 15c is an image of the left index finger. Figure 15d is an image of the left middle finger.Figure 15e is an image of the left ring finger and figure 15f is an image of the left thumb.

Figure 16 shows the images that are taken with the new setup. The figures are of the same finger/soap models and have the same size (638 x 340).

If the images of the old setup are compared to the images of the new setup, then the following can be noticed:

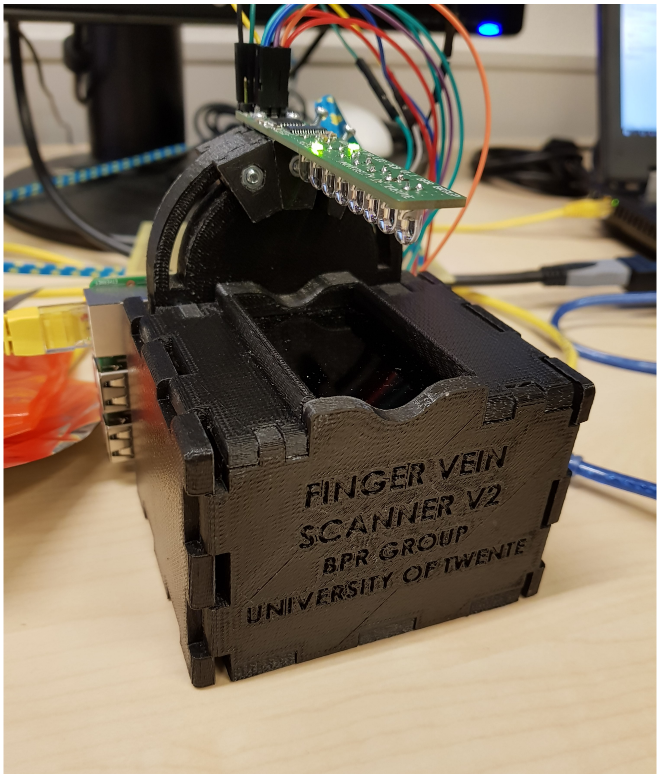
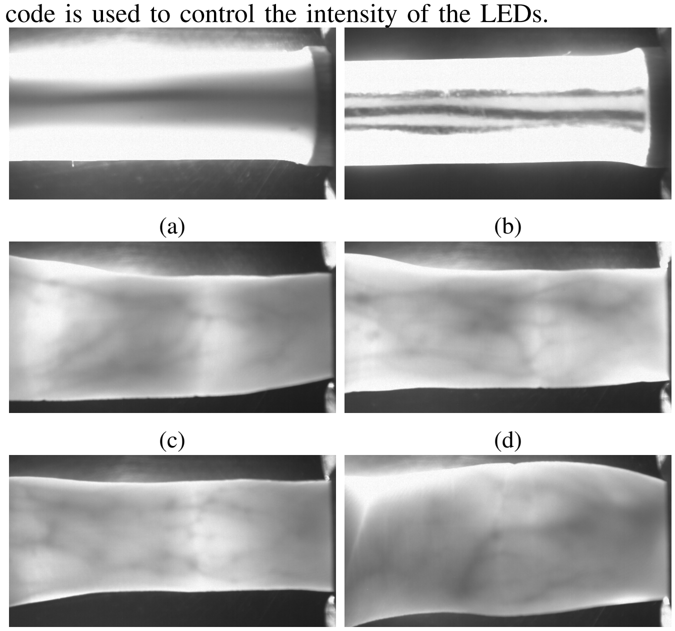


Fig. 14: The new finger vein scanner

- The background in the images of the new setup appear to be darker.
- The ’veins’ in the soap model appear darker with the new setup, but the ’finger tissue’ is darker as well.
- The finger tissue appears to be a little darker in the images of the new setup.
- The ’veins’ in figure 15b are over exposed. Especially the outer veins seem to disappear.
- The upper contour in the figures 15c, 15d and 15f are much brighter than the similar images of the new setup.

The values in table II are extracted by selecting a rectangular area in the image that only contains finger tissue or veins. From that area the GLCM is determined. With the function *graycoprops* the parameters ’contrast’ and ’homogeneity’ are extracted. The contrast in the images b of figures 15 and 16 is very high. This is also expected as the ’vein’ appears to be black and the surrounding tissue appears to be white. However, the contrast is slightly higher with the new setup (235.0 compared to 188.3). The overall homogeneity is higher with the new setup and the finger contours in the images of the new setup are less overexposed as well.

The histograms of the images in figures 15 and 16 are also plotted and can be seen in figures 17 and 18. It appears that the histograms c trough d of the images of the old setup are centered around a gray value of 170 to 180 while the respective histograms of the new setup are centered around 80 to 90. This is also what is expected if the mean gray intensity of the finger vein images should be about 80. Why the histograms of the old setup are centered around 170 to 180 instead of 80 to 90 is unknown and needs to be further investigated. As similar code is used to control the intensity of the LEDs.

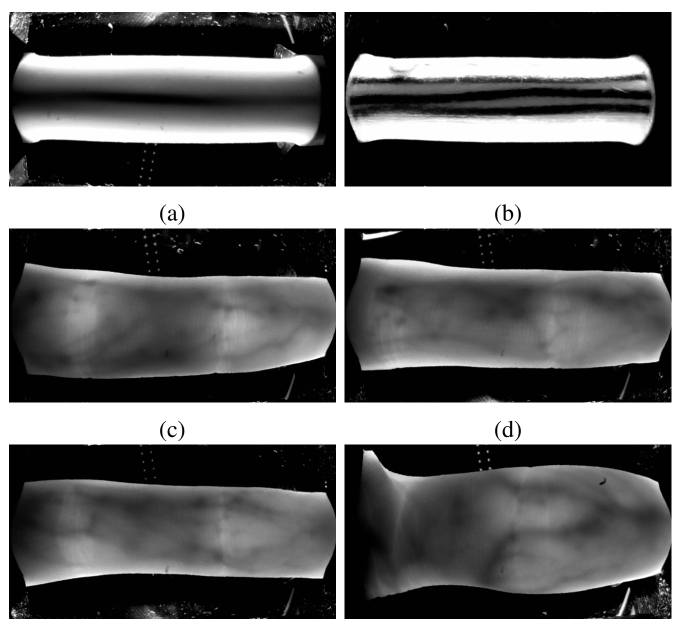


(a) (b)

(c) (d)

(e) (f)

Fig. 15: Finger Vein images captured with the old setup.



(a) (b)

(c) (d)

(e) (f)

Fig. 16: Finger Vein images captured with the old setup.

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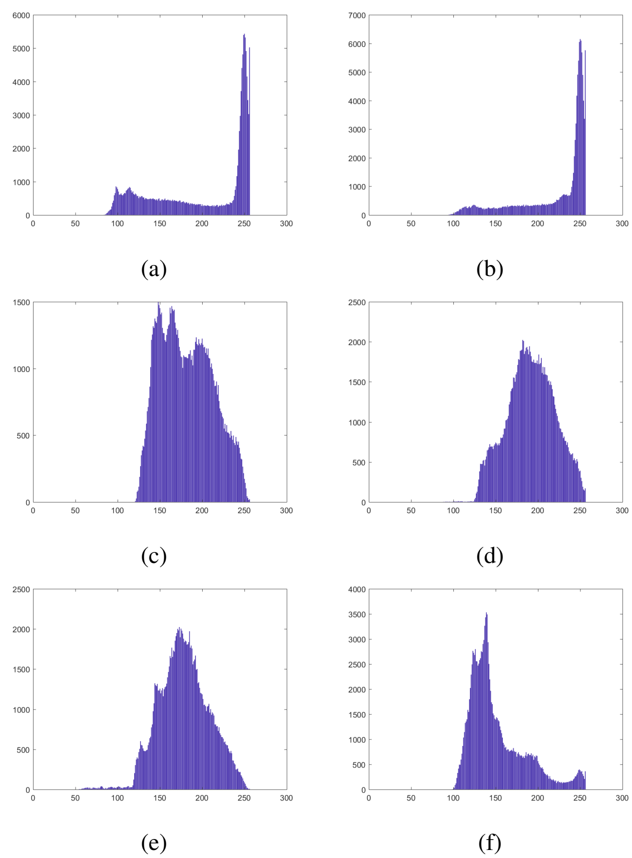

Fig. 17: Histograms corresponding to the images in 15

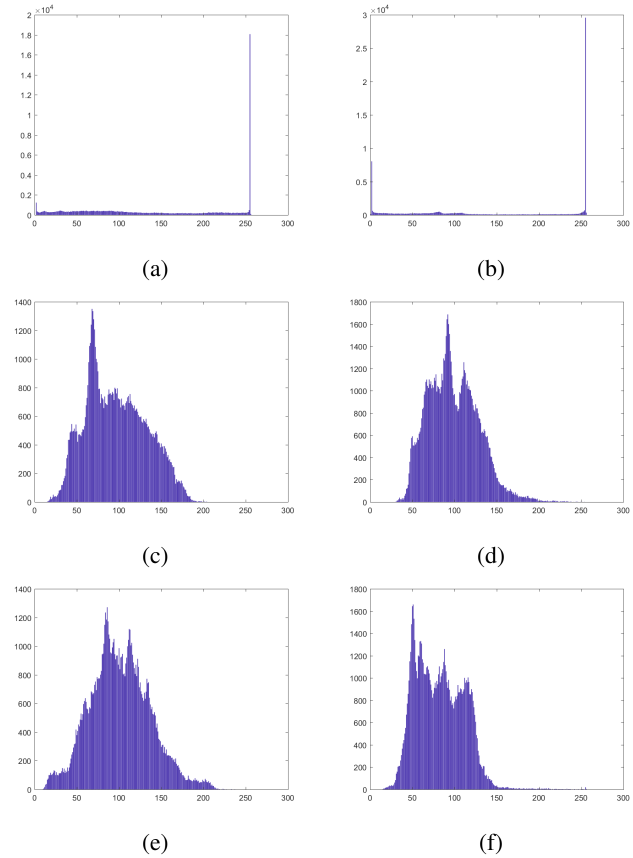

Fig. 18: Finger Vein images captured with the old setup.

Image	Contrast	Homogeneity	Overexposure
15a	50.68690	0.29297	0.1
15b	188.32568	0.24237	0.4
15c	39.57338	0.33478	0.7
15d	33.59627	0.34951	0.7
15e	18.65367	0.39920	0.8
15f	17.93329	0.39855	0.6
16a	57.35651	0.45421	0.6
16b	235.03573	0.56351	0.7
16c	21.22030	0.38620	0.9
16d	16.12588	0.40612	0.9
16e	8.45148	0.44425	0.9
16f	13.76876	0.41137	0.9

TABLE II: Scores for the images made with the old setup.

VIII. Conclusion

The goal was to design a finger vein scanner that was smaller than the old setup while it should maintain or even improve the image quality of the vascular pattern images. A new device is made that is indeed much smaller than the old device. The image quality of both devices seems to be similar. The new device has slightly better results when it comes to contrast and homogeneity. It does perform better when it comes to the overexposure of the finger contours. However, it is unknown if six images are enough to verify whether the image quality is better are not. Especially when it is uncertain if the illumination control was the same. The new device also gives options for future research. The IR LEDs can be re-positioned such that it can be investigated how the IR light scatters inside the finger for illumination from different angles. There are also three camera's in the design such that it is possible to make 3D reconstructions of the finger veins.

IX. Recommendations

A whole new device is made in which only the IR LEDs are the same. Hence, the components of the new device should be placed in the old device in order to evaluate the performance of each of the new components. Especially the IR pass filter and the camera should be tried out with the old IR light controller.

The new camera uses a rolling shutter. For the image quality it should be investigated if the PWM frequency(15625Hz) of the new IR light controller is indeed high enough. Even though the switching of the IR LEDs was not noticeable in the acquired images. Also, the new camera uses a lens that distorts the images a bit. The software can correct for this if the camera parameters are measured. This is not implemented yet.

The program that is used with the old setup is not structured at all, since many people worked on it and many different pieces of code have been written. A new clean program should be written to really now for sure that IR LED control is the same in both device. Or the old program should be cleaned up.

The IR pass filter plastic is placed a couple of millimeter below the finger. In a new design it might be wise to make this filter removable such that it can be cleaned. The finger prints that are left behind on this IR pass filter are not visible in the obtained images.

If a close look is taken on the finger vein images of the new device then also a fingerprint can be seen. This might give options to combine a finger vein scanner with a finger print reader. For instance if LEDs are used that do illuminate a finger but does not make the veins visible then the fingerprint can also be extracted with this device.

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Appendix A
Schematic IR LED PCB

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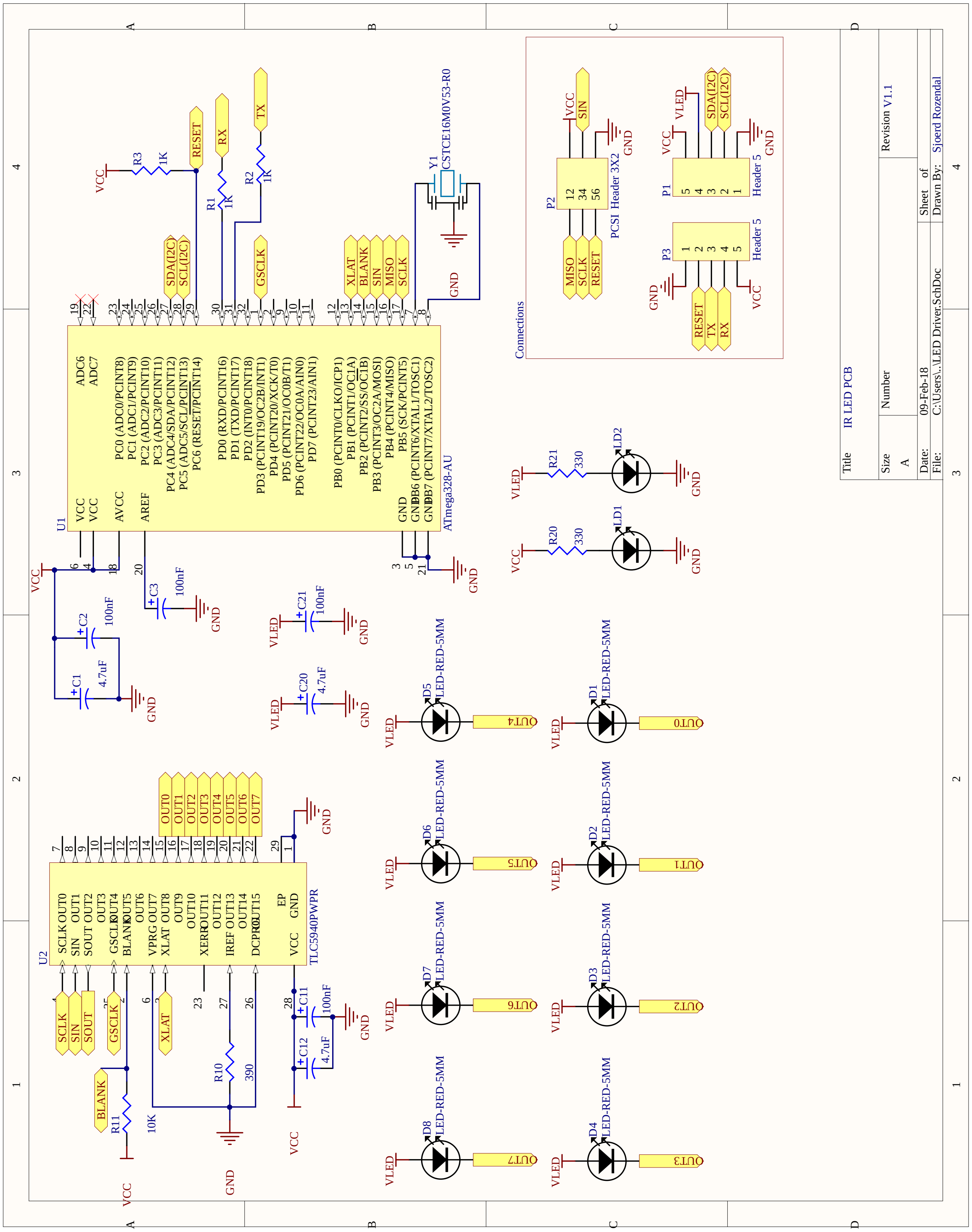

Fig. 19: Schematic of IR_LED_PCB

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