Finger Vein Pattern Recognition Using a Contact Sensor

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***Abstract*—Conventional vein recognition systems use cameras to obtain near-infrared finger vein images, but the size of these systems can be reduced if the image capture method is changed from a camera to a contact sensor. This study investigates the feasibility of a finger vein recognition system that uses a contact sensor, where the focus will be on what type of sensor is needed to achieve this and how large this sensor should be. To have a sensor with a large enough surface area to capture vein patterns a commercial camera will be converted into a contact sensor. To use this sensor multiple modifications are made to the original camera's PCB. Furthermore, several collimator designs are tested to see how this affects the projected light on the sensor and the visibility of objects placed in front of the sensor. The resulting images show visible veins when using phantom fingers that have known vein patterns. This shows that finger vein pattern recognition should be feasible if the necessary adjustments are made to the collimators.**

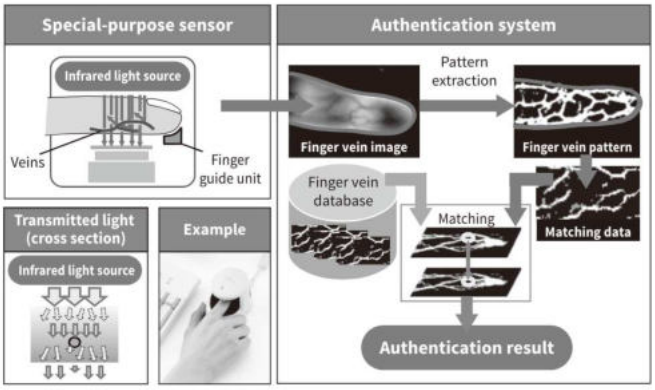


Fig. 1: Overview of finger vein authentication technology [3]

I Introduction

As advancements are made in the methods used to crack passwords the need for more advanced security systems increases. One of the areas that is expanding is biometric security systems. These systems eliminate the need for the user to remember passwords by using the user's body as the key to unlocking the system. Since every person has unique biometrics the person using the system can be identified by showing a part of their body. This can be something like their face, iris, fingerprint, or veins. Vein systems offer some distinct advantages over other biometrics: they are indifferent to skin surface conditions like dryness or cuts since they look at the inside of the body, they are harder to forge since they are only visible to infrared light making it hard to collect the biometrics without being close and having consent and lastly they can detect the liveness of the user by looking at the blood flow in the veins. [1].

A. Vein pattern recognition

To recognize a person's veins, Near InfraRed (NIR) light is emitted into the skin, which is then absorbed by the veins at higher rates due to the higher concentration of hemoglobin in the veins compared to the surrounding tissue. This results in dark spots where the light travels through the veins to get to the sensor.[2] This process can be seen in Figure 1.

After the image is acquired its quality is assessed to see if it is good enough to be processed further or if a new image needs to be made. The image is then preprocessed to counteract the used sensor's non-ideal behavior and make the veins more visible. After that, the Region of Interest (RoI) is determined. This ensures that only the finger itself is processed further, not the surrounding area. The RoI then has its features extracted either by directly using the binary representation of the image or by using Deep-learning-based techniques to interpret the RoI and extract discriminating features. Finally, the features are compared to the database to determine if the user is registered and if so what they should be able to access. [1]

The images are usually acquired using a camera but this does have a drawback: the camera needs space between the camera and finger to capture a sharp image. This is because lenses are placed in front of the camera to bend the light so that it is perpendicular to the sensor in the camera. If the camera is replaced by another sensor that can capture the veins the total size of the system can be reduced. This will result in finger vein recognition being a more viable alternative in devices where size is a constraint.

One possible solution is a contact sensor. These sensors use the same architecture as a camera but do not have the lenses in front of the sensor. Instead, the subject of the image is placed against the sensor. Normally pictures get blurred since the space between the sensor and the subject allows light not perpendicular to the sensor to shine on a different part of the sensor. If this space is minimized the blurriness can be reduced allowing the image to be used for vein recognition.

B. Image sharpness

Unfortunately, the space between the veins and the sensor can not be completely removed since the sensor has to look through the skin of the finger and the sensor needs a protective glass to not get damaged when in use. This means that the image will be blurry. If the image is too blurry to recognize the vein patterns a solution needs to be found.

A possible solution to blurry pictures are collimators. Collimators are grids of holes that only allow light to pass through when angled in a certain direction. This angle can be calculated by taking the inverse tangent of the diameter of the hole divided by the height of the hole. From this the size of the hole projected onto the sensor can also be calculated using the distance between the sensor and the bottom of the collimator.

Another way to solve this problem is by using encoded apertures which cast shadows on the sensor that can be decoded by solving a linear inverse problem.[4]. neural networks can also be employed to decode the images if given enough training data.[5]

C. Goals

This paper will try to answer whether capturing images that can be used for finger vein pattern recognition using a contact sensor is possible. To answer this question several things need to be figured out first. The first step is finding a big enough sensor to capture a finger vein pattern. Then The image quality is assessed and if this is insufficient the suggested solutions will be tested.

In section II existing systems will be covered as well as research that covers designs that can be implemented into this research. section III will delve into what kind of sensor should be used. section IV will build upon this knowledge and describe the steps taken to design the system which will then be tested in section V. Finally the problems of the system and further recommendations will be discussed in section VI and section VII.

II Related work

Research has been done into how contact sensors can be used to look at veins. Pakpuwadon et al. have developed a CMOS sensor that was placed on the brain of a mouse to see the blood vessels in the brain.[6]. In their paper they were able to see the blood flow in the vessels. This shows that it is possible to use a sensor without a lens to capture veins. The main difference between their setup and what is needed for a finger vein recognition system is that their sensor is placed directly on the mouse's brain while when looking at fingers the sensor has to look from the outside of the skin at the veins while having a protective layer over the sensor. This increases the distance from the veins to the sensor resulting in a blurrier picture due to the direction of the light not being perpendicular to the sensor. Another difference is the size of the sensor. Their sensor has a total pixel surface area of 1.92mm by 1.92mm while fingers are an order of magnitude bigger which means that to capture enough of the veins in the finger to recognize a pattern a bigger sensor is needed reliably.

In 2022 X. Pan et al. developed a Deep Neural Network (DNN) that when combined with an encoding pattern can reconstruct images without any lenses. The encoding pattern is placed in front of the camera and can be seen in Figure 2 together with the results of the reconstruction. In this figure the ground truth, captured image and reconstructed image are placed below each other while also being compared U-net and a model-based approach.

Fig. 2: Experimental setting and result. (a) Assembled mask-based lensless camera. (b) Result of image-on-screen experiment. (c) Result of object-in-wild experiment. Both the screen and objects are placed approximately 15 cm ahead of the camera. The proposed approach produces the most visually appealing images. The U-net [25] reconstructs images lacking details. The model-based approach is iterative optimization, employing ADMM [8] and total variation [26]. It reconstructs images with evident streaky artifacts and noises, and color distortion in some areas. The result of the proposed network without the attention part is listed in the last row.[5]

S. Rozendal [7] has developed a NIR LED PCB which can be seen in Figure 3. This LED PCB uses 8 850 nM NIR LED that are controlled using a TLC5940 PWM LED driver which is controlled by an ATMEGA328P-AUR microcontroller. This microcontroller can be communicated with via I2C allowing a device to send which LED they want to change and a value between 0 and 4096 to change the PWM signal from off to on. This system is ideal for this research since it allows for easy control of the illumination of the sensor and images of finger veins have been made using these LEDs.

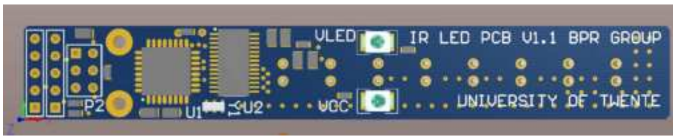


Fig. 3: LED PCB used to illuminate finger veins [7]

III Analysis

Several types of sensors can be used when capturing finger vein images. The three main sensors that can be used are InGaAs, CCD and CMOS sensors. These sensors have several advantages and disadvantages over each other. the main differences looked at will be the quantum energy which is the percentage of photons a sensor converts into electrons, the ease of use, and resolution.

InGaAs sensors are made to measure infrared light but the quantum efficiency of these sensors drops significantly below 900nm as can be seen in Figure 4. Another downside to the sensors is that they generate a lot of dark current. Dark current is the current that the sensor outputs when no light is shining on the sensor. This current is generated by the temperature of the sensor meaning that to use an InGaAs sensor the camera needs to be deep cooled to reduce the dark current.[8] This makes it hard to iterate on a design using this sensor since the cooling system needs to be adjusted each time.

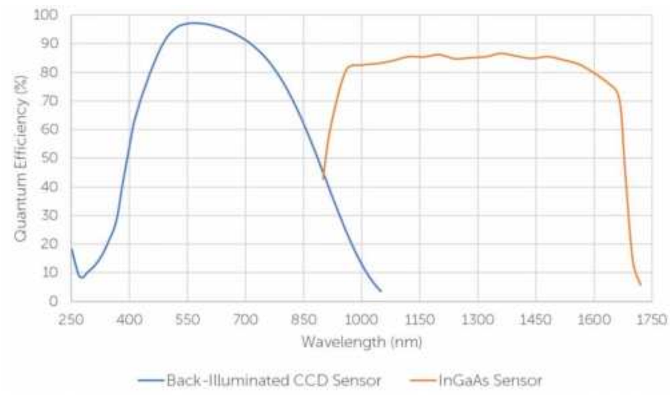


Fig. 4: Quantum efficiency of CCD sensor and InGaAs sensor [9]

A CCD sensor and a CMOS sensor use the same circuit to collect the light of each pixel meaning that they have the same quantum efficiency. From Figure 4 we can see that this is around 60% when at the desired 850nm wavelength used by the LED PCB.

The main difference between the two is that with a CCD sensor, the charge built up by the pixels is amplified at the output of the sensor whereas a CMOS sensor has an amplifier after each pixel allowing for faster transmission and readout speeds. This means that a CMOS sensor is better suited for liveness detection since the blood flow can be more accurately detected. Other advantages of CMOS sensors are the higher resolutions and low power consumption. They are worse in low-light applications but since the LED PCB can be easily adjusted to be brighter this will not affect the images.[10]

For the reasons given above a CMOS sensor will be used to acquire the images. Unfortunately acquiring a sensor large enough to cover a large enough part of a finger to see vein patterns is difficult. Most standalone sensors have either a surface area below 1cm^2 or are not within the budget of this research.

Luckily commercial cameras use bigger sensors that can be bought relatively cheap. The camera chosen for this research is the Lumix DMC-G6 which can be seen in Figure 5. This camera was chosen since it was available on short notice, has a four-thirds sensor which is a 17,3 by 13 mm pixel array and the data was available about how the components were wired in the camera. A full-frame camera would have been preferable since these cameras have a 36 by 24mm array but these were not available within the budget.

Fig. 5: Lumix DMC-G6 camera used to make the contact sensor[11]

IV Implementation

Before images of finger veins can be made several things need to be achieved. The first step is to make the CMOS sensor ready to be used as a contact sensor. Then a design has to be created to house the sensor and any extra parts needed to operate the sensor. Finally a lighting solution needs to be found to illuminate the veins.

A. Camera modification

To use the CMOS sensor as a contact sensor several modifications need to be made to the PCB and wiring. The first step was to make the exposed electronics safe to touch. This was done by desoldering the 300v 170µF capacitor from the flash circuit and the gate of the transistor used to charge the capacitor was shorted so no high voltage was generated. Then a 10KΩ resistor was placed in between the 5v supply line and the trace going from the flash PCB to the main PCB with the main control chip. This is done to simulate the correct voltage at the control chip when the capacitor is fully charged which is normally made by a voltage divider coming from the capacitor with a ratio of $\frac{16*10^3}{(910+910+300+16)*10^3} = \frac{2}{267}$. The flash itself was also desoldered to save space in the final setup. The resulting modified PCB can be seen in Figure 6 where the diagonal resistor labeled 103 is the 100KΩ resistor and the black wire is responsible for shorting the transistor gate.

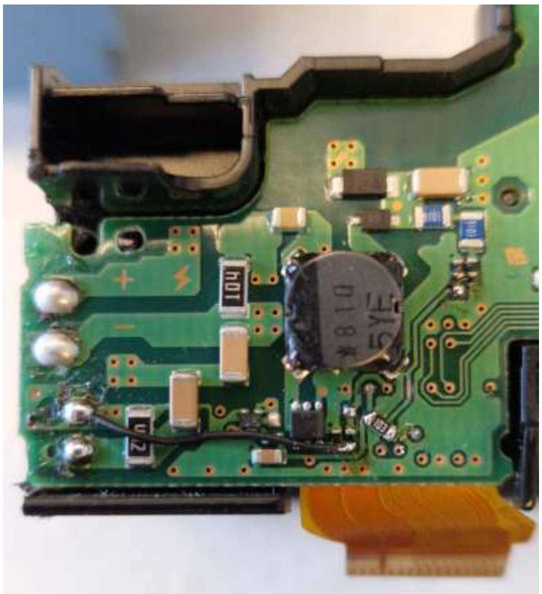


Fig. 6: Modified flash circuit

After that, all separate PCBs and components not needed for the system to function were removed. These are the viewfinder, The hot shoe, the lens attachment, the NFC connection, the Wi-Fi chip, and the microphone attachment. The components that needed to be connected were the sensor itself, the flash and battery PCB, the flexible top PCB, the LCD screen, the flexible backside PCB, and the shutter PCB. The shutter is not used to capture the images but the control system gives an error when it does not receive a signal back from the shutter when it is activated. This means that the shutter can not be removed without emulating the signal generated by the shutter circuit, which was deemed to be outside this research's scope.

The flexible top PCB was also modified to have a power switch and a wire to select the camera mode as can be seen in Figure 7. The frame of the camera normally made these connections but this was removed to give access to the CMOS sensor. The downside to this method is that selecting a different camera mode requires the wire to be desoldered and soldered into a different position. This is why the camera was set to manual mode where all settings of the camera can be changed via the LCD screen and the buttons on the backside PCB.

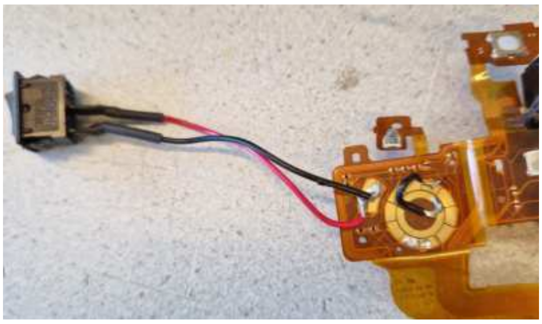


Fig. 7: Modified flexible top PCB

B. 3D model

To use the sensor, it is mounted to the underside of the 3D model shown in Figure 8 using the 3 holes shown in Figure 9. The 3D model is 3D printed in two parts the top part used to mound the LED strip covered in subsection IV-C and the main part that goes over the control PCB and sensor. The main part has an indent to guide the finger to the right position and blocks as much sideways light from the sensor while still fitting the control PCB under it.

To protect the sensor when in use a glass cover was placed between the 3D print and the sensor. The glass should be as thin as possible since the more space in between the sensor and the veins means that the image will be blurrier. This is why a piece of glass that is between 0,13 and 0,17mm is chosen. The glass is 22mm by 22mm, covering the entire sensor.

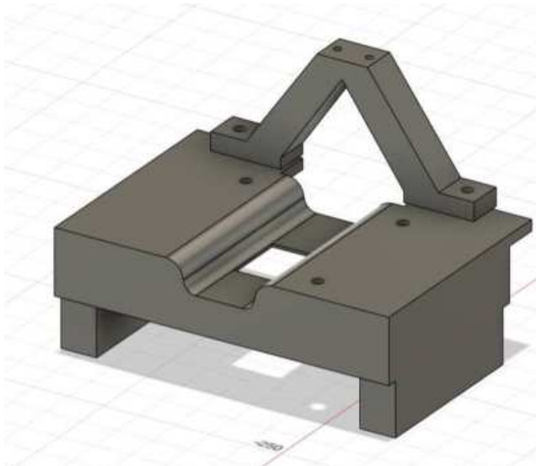


Fig. 8: 3D model of setup design in Fusion360[12]

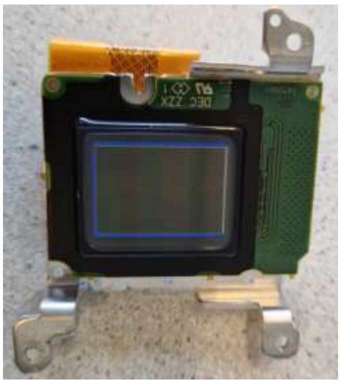


Fig. 9: CMOS sensor in DMC-G6

C. Lighting

To send data to the PCB an Arduino Uno reads out a 50KΩ potentiometer which is then converted to a value between 0 and 4096. This value is then sent to all the LEDs on the PCB. The code on the Arduino can be found in section IX. The LEDs of the PCB are powered using a 5V 2A power supply that is converted to 3.3V using a 2A voltage regulator. The ATMEGA328P is powered using the 3.3V pin on the

Arduino. The microcontroller and LEDs are not powered using the same input since the current spikes of the LEDs caused the microcontroller to turn off and reset again which turns off all the LEDs. This circuit can also be seen in Figure 10. The 2 data lines between the Arduino and the LED PCB each have a 4.7KΩ connected to the 5V line as a pullup resistor but these were not drawn to simplify the circuit.

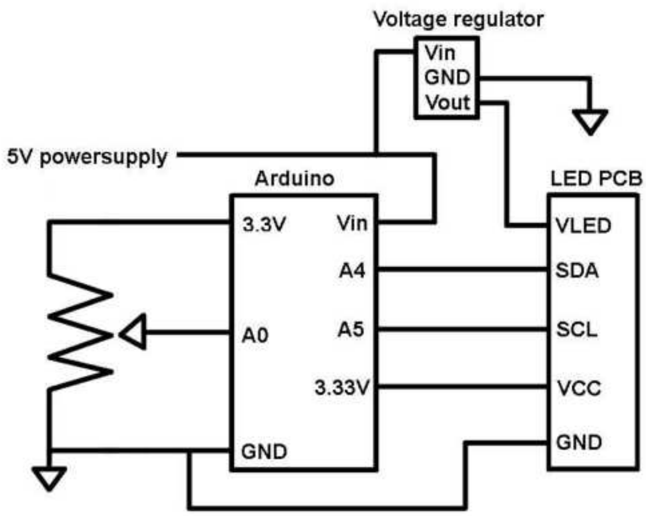


Fig. 10: Simplified circuit used to control the LEDs

The complete setup can be seen in Figure 11. When using this setup, a cloth was placed over it to block any light from outside sources.

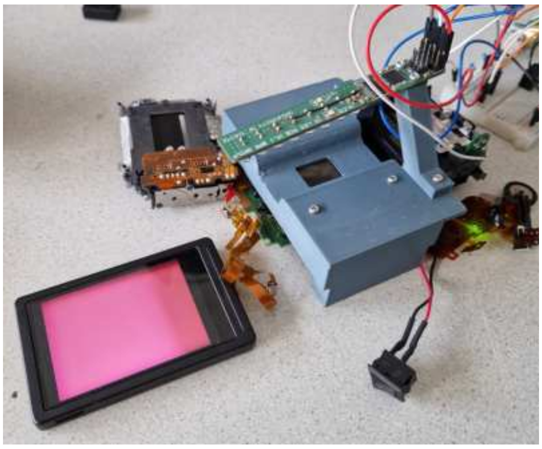


Fig. 11: Setup used to acquire Figure 12

V Experiments

To test the setup a cross with a thickness of 2mm was drawn on a piece of paper and then pressed down on the sensor using the index finger. This resulted in Figure 12.

Fig. 12: Image of cross captured using basic setup

Since the cross was visible the next step was to see if veins in a finger were visible to do this phantom fingers developed by L. Speeuwers et al.[13] were used. These fake fingers emulate veins in a real finger but the placement of the veins is known and always the same without needing to use the same test subject each time. The phantom finger used for testing in this work has a straight 1.2mm thick vein running across the entire finger as can be seen in Figure 13.

Fig. 13: Phantom finger used to test the system

A. Collimator optimization

When using the phantom finger the image was to blurry to see veins so several collimator designs were tested. The collimator must absorb as much light as possible so that no light will be reflected when it hits the walls of the holes. This is why the collimator is printed using black PLA.

The first dimension that was tested was the minimum diameter. The smaller this diameter the less spread out the light will be which will allow more holes to be placed next to each other without having the projections on the sensor overlap. To test this a collimator with different size holes was 3D printed. the model of this can be seen in Figure 14. The smallest hole that was able to be printed without the printer partially or completely filling the hole was 1mm.

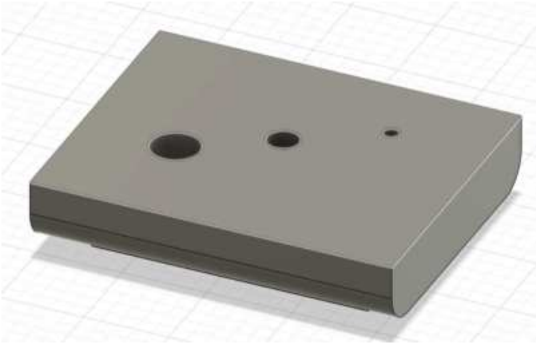


Fig. 14: Collimator used for testing the minimum diameter of the holes

Then the maximum amount of holes that can be placed in the collimator was tested. The maximum amount that was found was a 4 by 6 grid where a 3 by 5 grid was placed in between the bigger grid as can be seen in Figure 15.

Fig. 15: Top and side view of collimator

The next step is to determine what height the collimator should be. when considering a cross-section of the collimator and the space between the collimator and the sensor 2 similar triangles can be drawn the first going from the top of the collimator to the bottom 2 points and the second following the hypotenuse of the first triangle to 2 points on the sensor as shown in Figure 16. Since these 2 triangles are similar the ratios between the sides are also equal. This means that the expected projected size of the hole can be calculated by using the diameter of the hole, the height of the hole and the distance from the bottom of the collimator to the sensor.

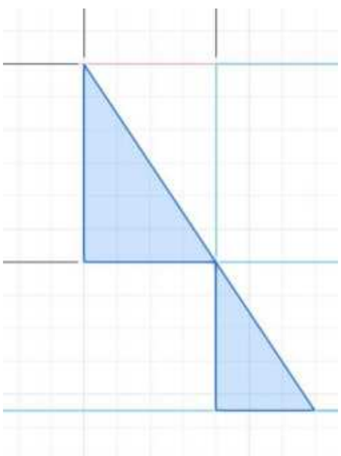


Fig. 16: Triangles used in calculating size of projected hole

The projected hole size can be calculated by multiplying twice the ratio between the hole diameter and height with the distance between the sensor and collimator and adding the hole diameter. This can also be seen in Equation 1 where Y is the projected hole size, D is the diameter of the hole, S is the distance between the collimator and the sensor, and H is the height of the collimator.

$$y = \frac{2 * D * S}{H} + D \tag{1}$$

The distance between the collimator and sensor can not be measured the only known fact is that the glass in between the collimator and the sensor is 0.13 to 0.17mm. This means that the minimum distance is at least 0.13mm. A conservative estimate of 0.30mm is used for the maximum value.

When plotting the projected hole size against the height of the collimator Figure 17 is acquired. From this figure it is visible that after 6 mm no significant improvement to the diameter of the projected hole is gained. This is why when testing the different heights of the collimators heights between 2 and 6 mm were tested with steps of 1mm.

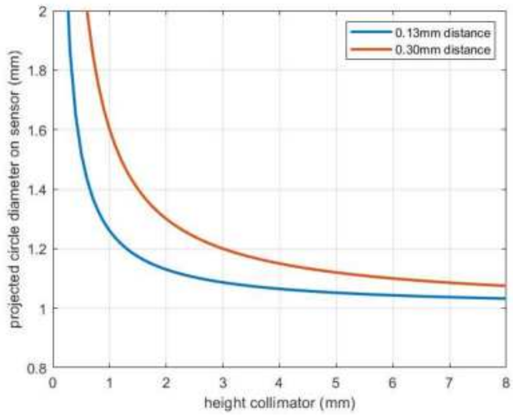


Fig. 17: Projected circle diameter against height of a collimator with a diameter of 1mm

The collimator is placed on the sensor as seen in Figure 18. When testing a finger was placed on top of the collimator and the brightness of the LED PCB was adjusted to not overexpose the sensor. Then a piece of cloth was placed over the setup and a picture was taken.

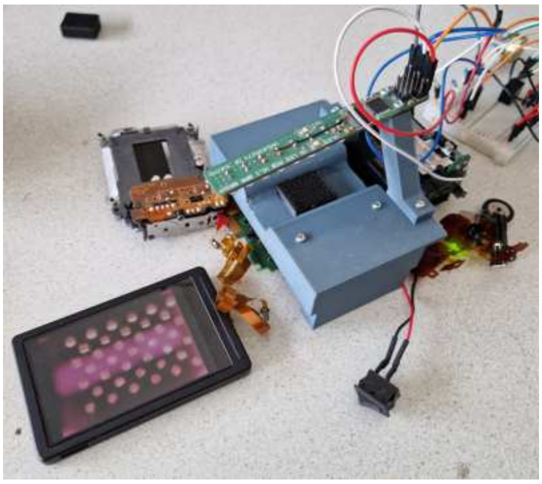
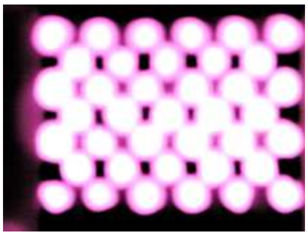
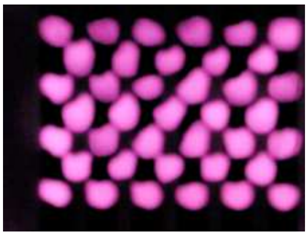


Fig. 18: Setup used when testing

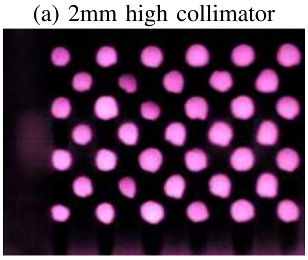
The result of the pictures taken with the 5 different collimators can be seen in Figure 19. The figure follows the expected result where the steps from 2 to 3 mm and the from 3 to 4 mm show significant changes in the diameter of the projected circle. While the later steps barely change the diameter.



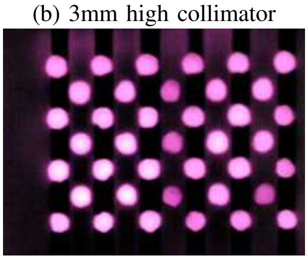
(a) 2mm high collimator



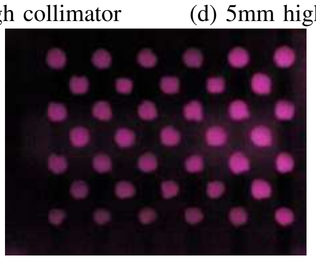
(b) 3mm high collimator



(c) 4mm high collimator



(d) 5mm high collimator



(e) 6mm high collimator

Fig. 19: Images captured using collimators ranging from 2mm to 6mm high

The 6mm high collimator was used to repeat the test that resulted in Figure 12 this resulted in Figure 20. here the cross can be seen so the next step was to test if the vein in the phantom finger could be seen.

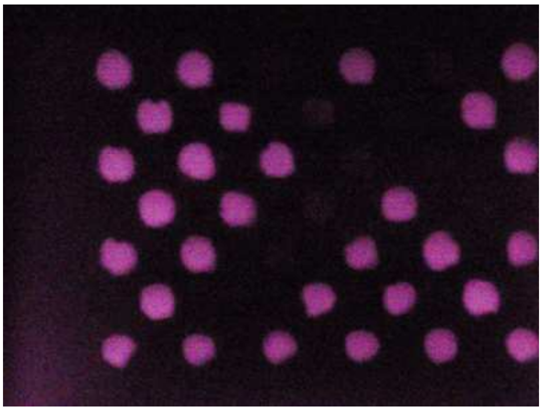


Fig. 20: Image of cross captured using collimator

The phantom finger was placed above the collimator and light pressure was applied. This resulted in Figure 21. where the vein can be seen in the last 4 holes of the third row. To show the difference between the holes where the a vein was and without the image was run through a threshold filter where each point below the specified value was turned black and above was turned white. this image can be seen in Figure 22.

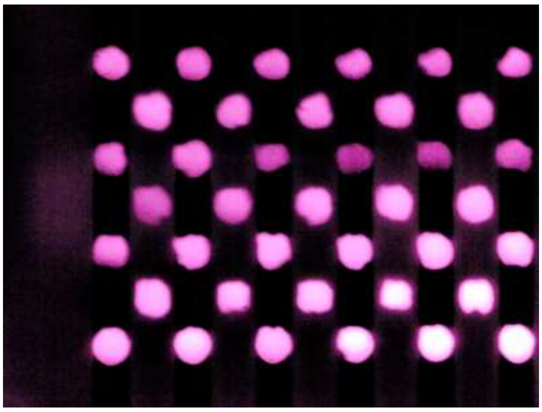


Fig. 21: Image of the phantom finger through a 6mm collimator

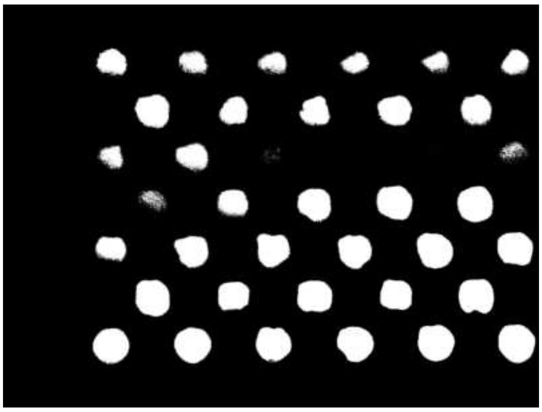


Fig. 22: Image of the phantom finger through a 6mm collimator with threshold

VI Discussion

The biggest bottleneck of this research was the quality of the 3D prints. The smallest hole that could be printed for the collimators using this printer was 1mm. This made it hard to see the veins of the phantom finger since these had a diameter of 1.2 mm which allowed light to pass through the hole if this was not exactly aligned with the vein. this can also be seen in Figure 21. The vein should be visible in all the holes of row 3 but since the vein was not completely straight in the finger the first 2 holes still allowed light to pass.

Another issue with the print is that the holes are not completely round which combined with the fact that the black filament still reflected some light made it impossible to validate Equation 1 with data since the error of the holes is in most cases bigger than the decrease in the projected circle size due to the increased collimator height.

These problems could be solved by using a different production method like resin printing instead of FDM printing since FDM printing struggles with small details while resin printing can achieve a higher resolution.[14]

Using a resin printer would also allow for a collimator with smaller holes. This would allow for more holes in the same area and a lower collimator to achieve the same angle as a higher collimator with bigger holes.

another thing that could be improved is using a matte black material for the collimator instead of the glossy black used for the collimators. This would allow more of the light that hits the wall to be absorbed instead of reflected to the sensor.

VII Conclusion

In this paper a sensor large enough to be used as a contact sensor has been found: a CMOS sensor from a commercial camera. While this sensor is not ideal for academic testing since no data is available on how to interface with the sensor itself and the internals of the sensor, images of veins in phantom fingers have been made showcasing the potential of contact sensors.

One of the main takeaway of this report is that a contact sensor can not be used on its own to capture images of finger vein patterns. Testing showed that using collimators to block light that is not perpendicular to the sensor greatly improved the visibility of the vein in the phantom finger. However more research should be done into collimators that are more densely packed whit smaller holes to see if smaller veins are using these collimators.

If the smaller collimators do not provide enough detail about the vein structure of a finger to accurately match it to data previously stored in a database further research could be done into image reconstruction using aperture coding and deep neural networks.

Improvements could also be made to the system by changing the material of the collimators to a more light-absorbing material since the filament that was used in this research still reflected some light from the wall in the collimators. Another minor improvement would be to remove the shutter and emulate the signal that the system checks for when trying to make a picture. This could also be taken a step further to design a control system that can interface directly with the camera but for that a description of how the communication protocol of the sensor works would be required.

VIII declarations

While preparing this work the author used the AI writing tool Grammarly to correct spelling and grammar mistakes. Furthermore ChatGPT was used as a starting point to find keywords to search sources. After using these tools the author reviewed the content as needed and takes full responsibility for the content of the work.

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IX appendix

```
#include <Wire.h>
int a = 0;
int b = 0;
int16_t LED_value = 0;
int potValue = 0;

void setup() {
  Wire.begin(); // join I2C bus (address
      optional for master)
  Serial.begin(9600);
}

void loop() {
//read value from potentiometer and convert
    into 2 bytes
  potValue = analogRead(A0);
  LED_value = potValue/2;
  Serial.println(LED_value);
  b = (LED_value >> 8) & 0x0F;
  a = LED_value & 0xFF;

delay(100);
//send to all LEDs
  for (int channel = 8; channel <= 15; channel
      ++) {


    Wire.beginTransmission(4); // transmit to
        device #4
    Wire.write(channel);
    Wire.write(a);
    Wire.write(b);
    Wire.endTransmission(); // stop
        transmitting
  }
}
```