Development of a Vein Detection Imaging System

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***Abstract*—Vein detection for use to provide imaging to assist in venipuncture can be performed using near-infrared light that captures backscattering of light, revealing the subcutaneous vein pathways. The use of contrast-limited adaptive equalization and filtering on raw image data acquired using LED sources measuring between 700nm and 1000nm demonstrates improved vein distinctions. The Hessian-Frangi vesselness filter can be leveraged to create vein maps that provide clear outlines of the vein pathways. The development of a low-cost vein detection imaging system demonstrates the ability to visually verify vein pathways and has the potential to provide greater accessibility for resource-restricted environments.**

Keywords—vein, venipuncture, near-infrared, imaging, optical, Hessian, Frangi

I. INTRODUCTION

Needlestick injuries, thrombosis, failure to access veins, and infection are common hazards and challenges that are associated with venipuncture procedures and medical treatments that involve accessing veins, to deliver medications and fluids or sample blood. Previous research and experiments demonstrate the feasibility of using near-infrared (NIR) light [1] and develop tools and methods to assist clinicians in identifying and visualizing veins with greater confidence and reliability than traditional methods [2]. The parameters and characteristics of vein finder devices, such as wavelength (color), camera sensor, distance from vein, and best usability practices [3].

Current products that already used in the market, such as VEINLITE® and AccuVein ® already provide reusable solutions that clinicians can use to identify these veins, however, at the time of this study, their flag ship products, the Veinlite LED+ and the AccuVein AV500, can cost upwards of $550 and $3000, respectively. Cheaper alternative options for vein detection and visualization are needed to increase accessibility to this technology.

The method of using light as a medium to characterize veins under the skin can be used for a variety of other different applications, such as biometric vein detection, detection and analysis of vein health, and the use of light to measure concentrations of various concentrations of interest in the blood, like pulse oximeters that use NIR light to measure oxygen concentration in the blood and pulse. The light rays emitted across the known spectrum, between 700nm and 1000nm can penetrate at different depths in the skin [4]. As light penetrates through tissue, light is absorbed, scattered, and reflected. The backscattering of light can be captured using a photosensor. With veins absorbing lighter than the surrounding tissue, a sensor will be able to differentiate between veins and lighter tissue.

The overall motivation for this project is to achieve a better understanding of using light and imaging sensors to visualize the arterial system under the skin throughout various parts of the body, using simple light-emitting diodes (LED) as a light source.

II. METHODOLOGY

A. *Scope*

The objective of this study is to develop the hardware and software to perform vein imaging and detection. Using near infrared light methods, the following workflow was performed.

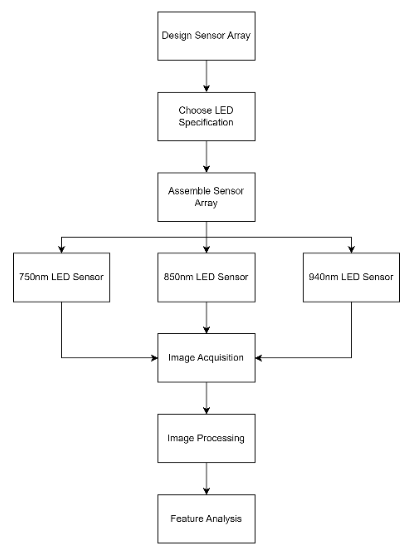

Fig. 1: Development workflow

B. *Materials*

The following materials were used to develop the system:

- Arducam CMOS IMX291 Module
- 750nm NIR LED
- 850nm NIR LED
- 940nm NIR LED
- 9V power supply
- MATLAB

The CMOS camera includes an infrared filter that must be moved prior to capturing images as this filter will filter the NIR light rays that is being leveraged to acquire the object image. The specific wavelength of each LED to be tested was chosen to acquire a range of different results between the known 700nm and 1000nm range that can sufficiently penetrate skin.

III. System Development

A. *Circuit Design*

A simple 8-LED array was designed with using a potentiometer to adjust the current controlling the light intensity of each LED.

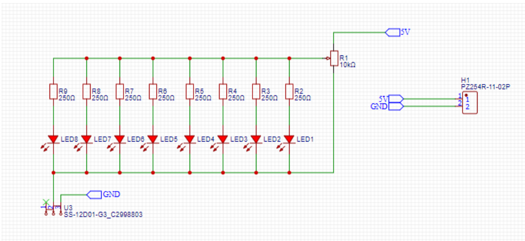

Fig. 2: LED schematic diagram

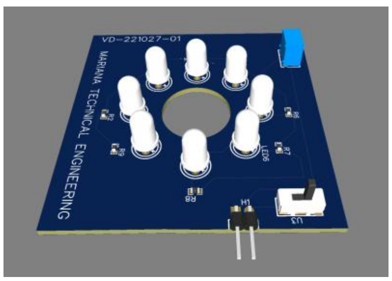

Fig. 3: Circuit board 3D model

B. *LED Array Configuration*

The Arducam sensor is an RGB CMOS module with lens that features a lock collar. Using the lock collar, the LED array is assembled to the camera module with the LEDs configured around the lens. To prevent LEDs from spinning in the assembly, a part was 3D-printed to secure LEDs into place.

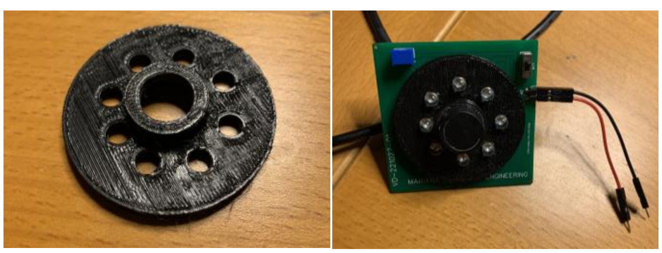

Fig. 4: Securement part (left), camera module with sensor assembly (right)

C. *MATLAB Algorithm*

The camera module assembly features a USB connection with universal drivers. The images were captured from the sensor and processed through MATLAB as 1080x1920 8-bit image objects, using the algorithm as shown below. The Hessian-Frangi Filter (HFF) was used on processed images to determine the impacts of the filter method.

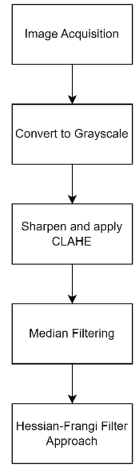

Fig. 5: Software Algorithm

1) *Grayscale Conversion*

a) Since the IMX291 sensor is an RGB color sensor, images received must be converted to grayscale prior to processing.

2) *Contrast-Limited Adaptive Histogram Equalization*

a) After the images are converted to grayscale, the image is processed using contrast-limited adaptive histogram equalization (CLAHE). Based on the statistical distribution of grayscale pixels, each pixel and its surrounding pixels are normalized. This normalization using a bilinear interpolation in the *x* and *y* axis helps to define object boundaries. In this case, the boundaries we are interested are the boundaries of the veins.

3) *Median Filtering*

a) Contrasting typically results in the amplification of noise as the high intensity values in pixesl are spread across when undergoing equalization. The median filter is used to reduce this noise.

4) *Hessian-Frangi Vesselness Filter*

a) After median filtering, the HFF is implemented to qualitatively analyze the algorithm's ability to provide the HFF with enough distinction in the vein boundaries to produce a vein map [5].

b) The Hessian matrix is calculated by taking the 2nd order partial derivatives, $\frac{\partial^2 f}{\partial x^2}, \frac{\partial^2 f}{\partial x \partial y}, and\ \frac{\partial^2 f}{\partial x^2}$, of the input image. The matrix is then convolved with a gaussian filter. The gaussian filter width can be adjusted by varying s. The eigenvalues of the resulting convolution is used to calculate a filter constant that is factored to each pixel in the image to prouce the final processed image.

$$H\big(f(x,y)\big) = \begin{bmatrix} \frac{\partial^2 f}{\partial x^2} & \frac{\partial^2 f}{\partial x \partial y} \\ \frac{\partial^2 f}{\partial x \partial y} & \frac{\partial^2 f}{\partial y^2} \end{bmatrix} = \begin{bmatrix} f_{xx} & f_{xy} \\ f_{xy} & f_{yy} \end{bmatrix} \quad (1)$$

$$g(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{-(x^2+y^2)}{2\sigma^2}} \quad (2)$$

IV. IMAGE ACQUISITION

The sensor was mounted to a fixed stand approximately 13 cm to 20 cm from the target surface of the body. Image acquisition was performed in a low-light setting to avoid additional light source interference. Voluntary images were taken of one male (M) and one female (F)

V. ANALYSIS

Using all three configurations of LEDs, veins were observable and detectable after processing the images using CLAHE and the median filter.

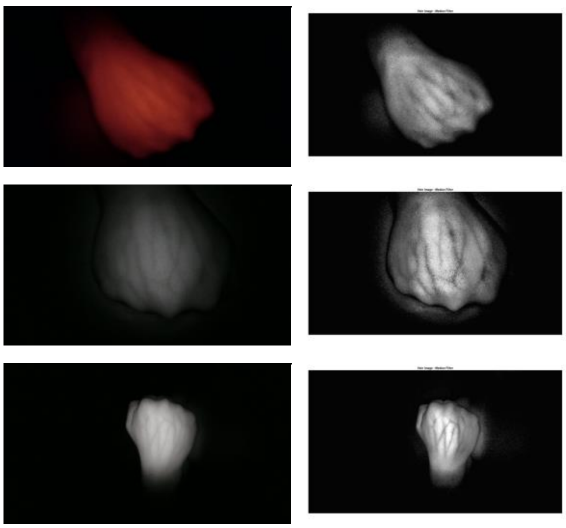

Fig. 6: (Left to Right, Top to Bottom) 750nm dorsal vein raw image, 750 nm dorsal vein processed image, 850nm dorsal vein raw image, 850 nm dorsal vein processed image, 940nm dorsal vein raw image, 940nm dorsal vein processed image

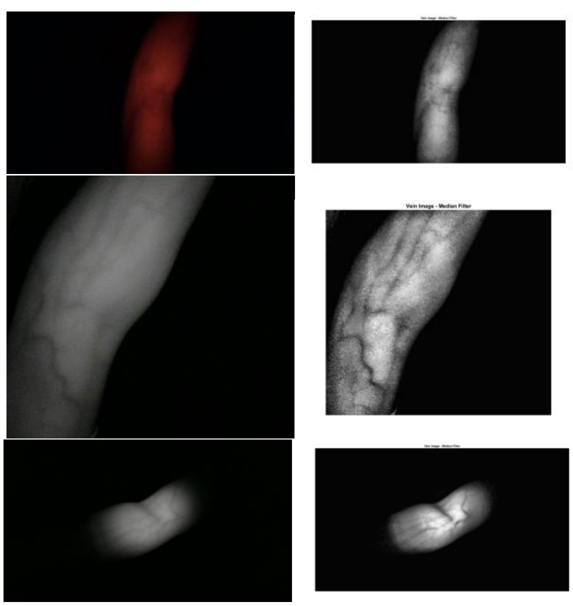

Fig. 7: (Left to Right, Top to Bottom) 750nm brachial vein raw image, 750 nm brachial vein processed image, 850nm brachial vein raw image, 850 nm brachial vein processed image, 940nm brachial vein raw image, 940nm brachial vein processed image

The HFF processed images demonstrate that, while some images were able to have some clear indication of the major vein pathways, further definition of object boundaries is required to further produce a clear map of the veins using the previous image processing methods.

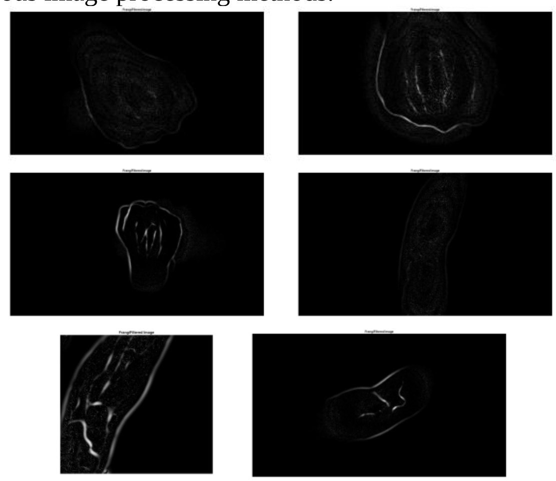

Fig. 8: (Left to Right, Top to Bottom) 750nm dorsal vein HFF image, 850nm dorsal vein HFF image, 940nm dorsal HFF processed image, 750nm brachial vein HFF image, 850nm brachial vein HFF image, 940nm brachial HFF processed image

VI. RESULTS

Overall, the developed camera and LED system demonstrates the ability to visualize and analyze vein pathways using NIR light generated from LEDs. The processing algorithm can be further improved to provide better line distinction of the boundaries of the veins in order to best leverage the HFF method. Upon qualitative analysis, higher wavelength and intensity light seem to be able to penetrate further into the skin. Further exploration in a combination of LED sources to produce more volumetric data should be explored to further optimize the ability to for HFF to identify tubular vessels.

Some improvements on the overall assembly design include creating a board configuration that can feature multiple LED configurations, measuring the saturation of light to best determine the fixed position from the surface of the body, and use a monochrome camera sensor to reduce noise.

The system was also successfully produced at lower cost than products already discussed on the market as shown below.

TABLE I. ASSEMBLY COST

Assembly Materials and Cost			
Component	***Unit Cost***	***Quantity***	***Cost***
Arducam CMOS IMX291 Module	$48.00	1	$48.00
750nm NIR LED	$0.08	8	$0.64
750nm NIR LED	$0.09	8	$0.72
750nm NIR LED	$0.68	8	$5.44
9V Battery	$4.70	1	$4.70
PCB Assembly	$2.00	1	$2.00
Total			$61.50

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REFERENCES

[1] Wadhwani, M., Sharma, A., Pillai, A., Pisal, N., & Bhowmick, M. (2016). Vein detection system using infrared light.

[2] Sakshi Ranade, Pratiksha Shetty, Kashish Yadav and Mita Bhowmick "Vein detection using infrared for venepuncture" Published in International Journal of Trend in Research and Development (IJTRD), ISSN: 2394-9333, Volume-4 | Issue-5 , October 2017, URL: http://www.ijtrd.com/papers/IJTRD10870.pdf

[3] Pan, C. T., Francisco, M. D., Yen, C. K., Wang, S. Y., & Shiue, Y. L. (2019). Vein pattern locating technology for cannulation: A review of the low-cost vein finder prototypes utilizing near infrared (NIR) light to improve peripheral subcutaneous vein selection for phlebotomy. *Sensors (Basel, Switzerland)*, *19*(16), 3573. https://doi.org/10.3390/s19163573

[4] Franky Chandra et al 2017 J. Phys.: Conf. Ser. 853 012019

[5] Dirk-Jan Kroon (2022). Hessian based Frangi Vesselness filter (https://www.mathworks.com/matlabcentral/fileexchange/24409-hessian-based-frangi-vesselness-filter), MATLAB Central File Exchange. Retrieved December 7, 2022.

[6] Longo A, Morscher S, Najafababdi JM, J ¨ustel D, Zakian C, Ntziachristos V, Assessment of Hessian-based Frangi vesselness filter in Optoacoustic imaging, Photoacoustics (2020), doi: https://doi.org/10.1016/j.pacs.2020.100200

[7] Jiaoying Jin, Linjun Yang, Xuming Zhang, Mingyue Ding, "Vascular Tree Segmentation in Medical Images Using Hessian-Based Multiscale Filtering and Level Set Method", Computational and Mathematical Methods in Medicine, vol. 2013, Article ID 502013, 9 pages, 2013. https://doi.org/10.1155/2013/502013

[8] Alejandro F. Frangi, Wiro J. Niessen, Koen L. Vinc and Max A. Viergever (1998), "Multiscale Vessel Enhancement Filtering", Medical Image Computing and Computer-Assisted Intervention — MICCAI'98 Lecture Notes in Computer Science 1496/1998: 130.

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