Method of peripheral vein detection using Electrical Impedance Tomography

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Abstract. The aim of the current contribution was to develop a method for locating arm veins in patients by using an electrical impedance tomography. Eight surface electrodes were placed on a simulated arm, separated at a fixed and equal distance from each other. The electrodes fed information about electrical impedance (conductivity) to EIDORS software. The three main phases (veins, muscle, and bone) each have different conductivity, which the device and software convert into a colour-coded tomograph displayed on a screen. The colour for blood on the image is previously set (in this case, red), revealing the location of the veins in the selected section of the arm. A sample run was made, successfully finding the correct location and size of the modelled vein, thus demonstrating the accurate operation of the device.

1. Introduction

Of the approximately 500 million venipunctures carried out annually in the world, 2.7-4.8% are not performed successfully on the first attempt, according to recent studies. This translates into around 15,000 patients per day that are subjected to unsuccessful perforations for the extraction of blood or insertion of fluids, causing unnecessary discomfort and pain [1, 2].

Generally, the method of palpation and visual identification is used to find a vein to be punctured. However, some factors make venipuncture difficult, including overweight, vascular tone, vein diameter, and varicose veins. The skill of the person puncturing the vein may also be relevant [1].

Some devices have been designed to solve the problem of locating peripheral veins of the arm, forearm and hand. For instance, infrared detectors [3, 4, 5] show veins with near infrared light (700-1000 nm) [6, 7]. Additionally, high-resolution ultrasound scanners provide a very good quality image in real time. Although these instruments are effective, they are relatively expensive. The venography technique can also produce images, but requires the injection of a contrast agent.

A novel and economical technique is electrical impedance [1], which was presently tested with surface electrodes to locate veins by means of the 4-point method with the injection of a fixed electrical current.

In this work, a simulation of an alternative method to locate peripheral veins that uses Electrical Impedance Tomography (EIT) was made, by means of 8 Ag/AgCl surface electrodes. Unlike the simple impedance methods [1, 8], the proposed method displays an EIT image of the
2. Materials and methods

2.1. Electrical Impedance Tomography

EIT is an economical non-invasive imaging technique that can be a valuable tool for medical diagnosis [8]. For image construction with EIT, a low frequency electrical current is applied to an object and the resulting electric field on its surface is measured (Figure 1). The pattern produced by the injected electrical current allows a series of electrodes to make a set of readings of electrical potential, which are recorded from the boundary of the conductive region [10]. This data on the distribution of conductivity is fed into a computer or EIDORS software to generate an image [9]. Although a computer furnishes a very accurate topograph from the measurements made of the overall distribution of conductivity [11, 12, 13, 14], the most common way of displaying images is with EIDORS software [15, 16, 17].

The main equation for EIT is [8, 15]:

$$\nabla (\sigma \nabla \phi) = 0 \in D$$ \hspace{1cm} (1)

Where $\nabla$ is the gradient operator, $\nabla \phi$ represents the static electric field, $\sigma$ is the conductivity of the body, $\phi$ expresses the electric potential, and $D$ is the body to be imaged [8, 15]. There are two processes involved in EIT, a forward problem and an inverse problem. In the forward problem, the initial conditions of conductivity are proposed, a current $I$ is injected to find a potential distribution, and equation (1) is resolved to calculate the potential $\phi(x, y) \in D$. In the inverse problem, an error between the computed potential $\phi(x, y)$ and the experimental value in the forward problem is compared until it is minimized [15, 16].

For the EIT technique, AC electrical current is injected into each pair of electrodes in region $D$ in order to measure a set of potentials between them (1). The distribution of conductivity inside of region $D$ is given by equation (2):

$$\sigma = \sigma_{\text{real}} + i \sigma_{\text{complex}}$$ \hspace{1cm} (2)

where $\sigma_{\text{real}}$ corresponds to the conductivity of the material and the $\sigma_{\text{complex}}$ corresponds to its permittivity. In this study, only the $\sigma_{\text{real}}$ of equation (2) was reconstructed because of the nature of the phases inside the arm. While veins and muscle are very conductive, bone is not. The permittivity of the phases was not used.
2.2. Linear EIT with 8 electrodes

Most applications of EIT are for a circular distribution or region (see Figure 2). Accordingly, a ring of electrodes is attached around the surface area to be analyzed. However, the measurement of the current study was made at the surface of the skin, making open linear distribution more appropriate. The EIT obtained from this configuration is only a section of that resulting from the electrode ring configuration of a circular distribution. Since the present region of interest (a part of the arm) for the tomographic image is relatively small in size (no more than a 10 cm long), the proposed number of electrodes is only 8. A larger number would not be feasible.

Due to the square configuration of the screen a finite element grid of 360 elements was considered to solve the direct and inverse problem in the modeling. So a square configuration is used to model and solve the EIT in this work. Adjacent pattern stimulus for injection of current \( I \), adjacent measurement of the potential \( \phi \) and 0.5 mA peak (1 mA peak) were used.

A simplified model for the linear reconstruction method is expressed in equation (3):

\[
[\sigma]_{360 \times 1} = [J]_{360 \times 40}[\phi]_{40 \times 1}
\]  

(3)

Where \( \sigma \) is the vector of conductivity for the inverse problem of the image reconstruction method, \( J \) is the Jacobian matrix of the system, and \( \phi \) is the vector of the measured potentials of the surface [14]. In this case, \( \sigma \) has size \( 360 \times 1 \) because the finite element mesh on EIDORS software contains 360 triangular elements; \( \phi \) is the measurement potentials vector, that contains

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**Figure 2.** EIT with an open electrode configuration.

**Figure 3.** Electrode position and display of the location of veins near the surface of the arm.
40 independent measurements because a maximum of 5 independent measurements are made in an 8 electrode configuration for an adjacent current injection [15], it makes a total of 5 \times 8 independent measurements; and finally the jacobian \((J)\) size is 360 \times 40 due to the mathematical model configuration.

A practical example of the scanner position for sensing the potentials involved in EIT imaging is illustrated in Figure 3. The image of the veins is displayed on the screen of the EIT scanner.

2.3. EIDORS

EIDORS (electrical impedance tomography and diffuse optical tomography reconstruction software) is designed to generate EIT images [17]. It processes a finite number of potential measurements of the conductivity and permittivity of an object and displays an image of electrical impedance distribution on a screen. The conductivity distribution was employed in the current study because blood conductivity \((0.67 \text{ S/m})\) contrasts with that of muscle \((0.23 - 0.63\text{ S/m})\), fat \((0.036\text{ S/m})\), bone \((0.006\text{ S/m})\) and skin \((0.00012\text{ S/m})\) [19]. The 3.10 with Netgen 5.3 version of EIDORS was presently run on MATLAB\textsuperscript{©}. It contains a lot of demos in \textit{m} language.

2.4. Method for scanning and displaying the position of the veins

After considering all the aspects of EIT methodology, the most appropriate ones were selected to design a new scanner for locating surface veins. The procedures are described hereafter.

(i) Eight Ag/AgCl electrodes are attached to the surface of the skin to detect the location of the veins in that area. It is very important to ensure contact of the electrode with the skin for the measurement of electrical potential. The distance \(k\) (in \text{cm}) between electrodes (\textit{e.g.}, 0.5\text{ cm}) and the radius \(r\) of the electrodes must be taken into account.

(ii) The position of the electrodes is established to normalize the scanned region to a rectangular model of \(a \text{ cm} \times b \text{ cm}\) (example: 4\text{ cm} \times 3\text{ cm}).

(iii) The EIT technique for the detection of conductivity is applied (real part measurements of impedance), and the image is reconstructed on EIDORS software. The parameters proposed for this method are: current = 1 \text{ mApp}, frequency = 1 \text{ KHz} (or some typical value used in EIT), with a sinusoidal pattern. The device is held at 0\textdegree and used with the synchronous demodulation method.

(iv) The EIT of the evaluated region is displayed as a colour-coded map on a screen, with each colour portraying a certain magnitude of conductivity.

(v) The desired vein is located on the screen in the colour representing the conductivity of blood.

(vi) The electrode position is the reference point for locating the vein.

EIDORS software reconstructs the tomography based on the surface measurements of electrical potential with the mathematical model chosen and the values established for the injection of current. Other configuration parameters are at the default settings, considering the finite element method used to solve the forward problem, the triangular shape of the finite elements, iteration procedures, and linear and nonlinear reconstruction methods. The EIT technique requires a physical EIT tomograph.

3. Results

The implementation of the method herein designed was simulated with EIDORS software run on MATLAB\textsuperscript{©}. The following parameters were used: an electrode contact impedance of 0.01 S/m, 8 electrodes, a 2 mm separation of the electrodes, and an adjacent injection of
current. Additionally, conductivity was normalized for muscle (1S/m), blood (1.44S/m), and veins (0.776S/m) and the device was prepared with the following settings: bones (modelled = 2), muscle (modelled = homogeneous), veins (modelled = 1).

The forward problem was modelled with a finite element mesh, two circular areas for bones, and a vein inside a muscle region, as found in a human arm. The inverse problem was solved with the Jacobian method on EIDORS to achieve an EIT where the vein is clearly visible and easily located with high contrast. The EIT display clearly showed the position of the vein, as illustrated in Figure 4.

A map of the three main phases of conductivity (generated with EIDORS software) was viewed in high contrast and printed for reference (Figure 4). The position of the vein in the reconstructed EIT image corresponds to the position of the modelled vein. The electrical impedance of the vein is clearly distinguishable from that of other phases, such as muscle.

The area determined for the simulation presented in this work was 15 cm in the y and 16 cm in the x axes for the forward solution, but only a mesh of 10 cm in the y and 12 cm in the x axes was considered for the inverse problem. The cross-sectional area for the simulated vein was $19.6 \times 10^{-6} m^2$, reflecting a modelled radius of 2.5 mm. Hence, the EIT imaging method presents an accurate display for locating veins of this size.

The technique under study produces the image of the position of the vein even when the high impedance of the skin is considered (see Figure 5). The position of the vein is clearly identifiable due to its contrast with other tissues of the forearm. Even though the contrast increased for the vein, it decreased for the bones. High-impedance noise also appears in the image.

4. Discussion
The results of the simulations show that it is possible to locate the position of veins with EIT. As veins are low impedance bodies (high electrical conductivity), they are distinguishable from bone, muscle, and fat, and therefore detectable on the display of EIT. The high contrast of the tomographic image accurately shows the vein in its modelled position. One of the factors justifying the development of this method of vein detection is that the venipunctures are difficult in obese patients, therefore not only the bone and muscle but also fat is considered in the simulation. When the skin is considered in the simulation, the reconstructed image shows that the vein is still distinguishable in the image, but other high impedances introduce some noise to the image. The vein remains recognizable due to its low impedance, which is easily located on

Figure 4. Vein detection with EIT.
the image due to its contrasting color on the impedance tomography. Since the objective was to establish a method to visualize the position of veins on a square screen scanner, EIT is presented in square geometry. However, the EIT technique can be implemented without much difficulty in a circular or elliptical geometry as in generic applications of the technique. However, it should be noted that the circular geometry type is widely reported in the literature as one of the main geometries.

5. Conclusions
A new method was tested for the detection of peripheral veins based on EIT. The data captured by the electrodes was converted into a tomograph with EIDORS software. The distinct conductivity of the veins versus that of muscle, fat and bone resulted in a high-contrast image displaying a vein of $19.6 \times 10^{-6} m^2$ in the correct position. The next step is to evaluate the new method with electrodes on a real arm to produce a real EIT tomograph.

References
[1] Al-Harosh M and Shchukin S 2017 J. Electr. Bioimp. 8 79–83
[2] Ganesh S 2007 Depth and size limits for the visibility of veins using the veinviewer imaging system. Master’s thesis University of Tennessee and University of Memphis.
[3] Lee J, Moon S, Lim J, Kim K, Lee J H, Gwak M J and Kim K S 2016 A finger-vein imaging and liveness detection for identity authentication using 2-axis mems scanner. 2016 International conference on Optical Mems and Nano photonics (OMn).
[4] Jayaprabha T and Suresh A 2016 Blood flow, vein and nerves detector using an nir sensor with estimation for embedded signal processing. 2016 International Conference on advanced Control and Computing Technologies (ICACCCT).
[5] Al-Ghozali H, Setiawardana and Sigit R 2016 Vein detection system using infrered camera. 2016 International electronics symposium (IES).
[6] Pan C T, Francisco M, Yen C K, Wang S Y and Shue Y L 2021 Sensors 19 URL Doi:10.3390/s19163573
[7] Ahmed K, Habaebi M and Islam M 2018 Indonesian journal of electrical Engineering and Computer Science. 10 URL DOI: 10.11591/sijeecs.v10.i1
[8] Zhang X, Xu G, Zhang S, Li Y, Guo Y, Wang Y and Yan W 2014 IEEE Trans. on Magnetics.
[9] Molinari M 2002 High fidelity imaging in electrical impedance tomography. Ph.D. thesis University of Southhampton.
[10] Polydorides N 2002 Image reconstruction algorithms for soft-field tomography. Ph.D. thesis University of Manchester Institute of Science and Technology.
[11] Adler A 1995 *Measurement of pulmonary function with electrical impedance tomography* Ph.D. thesis Universit de Montral
[12] Li T, Isaacson D, Newell J and Saulnier G 2013 *Journal of Physics Conference Series*.
[13] Cheney M, Isaacson D and Newell J 1999 *SIAM review*. 41 85–101
[14] Polydorides N and Lionheart W 2002 *Measurement Science and Technology*
[15] Holder D 2005 *Institute of Physics Publishing*.
[16] Lionheart W 2005 *Physiol. Meas.*
[17] Adler D and Lionheart W 2006 *Physiol Meas.* 27 S25–42 URL doi: 10.1088/0967-3334/27/5/S03
[18] Olson W H 2021 *Medical Instrumentation Application and Design: Electrical Safety* (John Wiley and Sons) chap 14, pp 638–674 4th ed
[19] Mueller J and S Siltanen 2012 *Linear and nonlinear inverse problems with practical applications* (Society for Industrial and Applied Mathematics.)