Wrist Pulse Determination Using Electrical Impedance Measurements

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Abstract – The present paper presents the results of a study to determine the feasibility of the determination of pulse at the wrist level using electrical impedance measurement method. In the cross section of the hand at wrist level the pulsating artery was modeled by a generic unit area conductivity change. The dipole model of the electric field change by a unit area of increased conductivity was used for a 2D electric field simulation. The field changes by geometry deformation and shifting bone position in the cross section as a result of hand motion is shown to be on the same order of magnitude as the blood related changes. The electric simulation data are encouraging for practical application of the method. More research is necessary to reliably separate motion artifacts from pulse data.

Keywords: pulse determination, wrist electrical impedance, geometry deformation induced field changes.

I. INTRODUCTION

The main objective of the work reported in the paper is the feasibility of pulse rate determination from electrical impedance measurement at the wrist level.

The study concentrated on boundary voltage drops changes due to pulsating blood in the wrist cross sectional anatomy in human subjects.

In order to prove the possibility and reliability of using the impedance method in practice a simulation using FEM (finite element method) tools was performed. The current distributions in a cross section at the wrist level of a human hand was calculated considering two current injecting electrodes on each side of the artery position.

Also simulations where carried out to determine the difficulties encountered in devising processing solution for practical applications using the local the conductivity variations when probed with almost uniform current distributions. The recent results obtained by research groups interested in electrical impedance imaging problem are based on theoretical models accumulated over time obtained by mathematical investigations [1].

The best and appropriate field patterns and data collection arrangement is known to be very important in electric impedance applications. Several particular patterns have been explored only and some have been studied to be associated with appropriate practical tactics of implementation [2].

The method mostly used recently in the electrical impedance imaging problem is formulated from a global functional perspective as boundary injected current fields and voltage measurements in the proximity of the imaging target area [3].

In the present paper an impressed almost parallel current density field configuration was devised by electrode placement considering the localisation of the artery in cross section. The almost homogeneous parallel field pattern is characterised by simplicity and ease of practical implementation. The error resulting from this simplifying assumption is not significant if only the estimation of the pulse rate by impedance variations is considered.

For the application considered of wrist pulse determination, a pulsating unit diameter circle was used to model the effect of blood surges in the artery induced conductivity non homogeneity.

A unit area of changed conductivity from background was considered a good approximation of the cross section of the artery.

A derivation of the dipole analytical model was devised recently for unit area of changed conductivity from background. The model was derived in principal based on the charge distribution at the boundary of the generic non homogeneity generated by the boundary field continuity constraints [8].

For the general case of electric current flow in domains with piece-wise conductivity distributions the literature is not abundant with results. The equivalence of the problem with the electrostatic and circuit representations is the method most often used to devise solutions [6].

The boundary voltage measurements are shown to be sensitive to conductivity changes due to artery diameter modifications. The results reported in the present paper are based the dipole model of non

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homogeneity induced change as a valid model for the increased diameter of the artery during pulse.

The geometry changes by deformation of the cross section shape and bone position shifting is shown to be on the same order of magnitude as the blood related changes. This aspect makes the pulse determination feasible in practice but nonetheless a very challenging task.

We considered the anatomy of the wrist composed of a homogeneous block of muscle, penetrated by three circular – shaped blocks: two representing the bones and one representing the artery as presented in Fig. 1. Simulations have been carried out for 3 possible cases as follows:

1. The basic normal case, the wrist is at rest, with both:
   a. blood flowing through the artery
   b. no blood flowing through the artery (the artery area being declared as muscle)

2. A modified geometry of the wrist, modeling the movement of the arm in action in cross section:
   a. blood flowing through the artery
   b. no blood flowing through the artery (the artery area being declared as muscle)

3. A total-modified (left and right) view of the wrist, considering both deformation due to movement of the arm and bone position change:
   a. blood flowing through the artery
   b. no blood flowing through the artery (the artery area being declared as muscle).
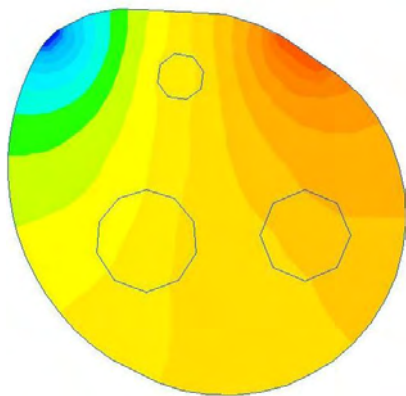

Fig 1. Constant potential lines image for the wrist geometry attempting to capture a blood conductivity variation change.

In the formulation of the cross sectional area resistivity geometry the following common values of resistivity of human tissue as found in recent literature was used [3], [4].

Table I

Tissue conductivities used in the model
(ohm.cm)

Blood	75
Muscle	200
Skin	200
Bone	2000

II. DIPOLE MODEL FOR THE CONDUCTIVITY CHANGES OF A CIRCULAR AREA IN AN ALMOST PARALLEL FIELD

The dipole model is an appropriate model for a unit area conductivity change from the background in electrical impedance physiological activity monitoring applications. The high contrast conductivity case is not specific to the target application of the paper and was necessary to be address .

In a impressed close to uniform and parallel current field the change due to the presence of a small generic unit area non homogeneity in conductivity results in a dipole like field added to the original one. The derivation of the equations of the added field is similar to the formulation of the problem in terms of electrostatic field [7] .

The electrostatic formulation of the problem for an *infinite conductivity* generic unit non homogeneity in a parallel electrostatic field is the case most often found in literature [5].

 The case of a *momentary small conductivity* change with respect to the background as it is necessary in the case of the application of the determination of the pulse from impedance measurement at the wrist level is detailed in the following. The set of equations is equivalent to the electrostatic case. In this case however it relates current density normal to the non homogeneity boundary of changed conductivity rather then the electric field intensity.

The formal similarity of the two permits a determination of the filed equations by imposing the continuity condition at the boundary of the conductivity discontinuity.

The current density continuity condition at the boundary results in a electric field discontinuity therefore a charge distribution $q\mid_{r\,=\,r0}$ must be accounted for as indicated in Fig 2. and mathematically described by equations (1 - 4).
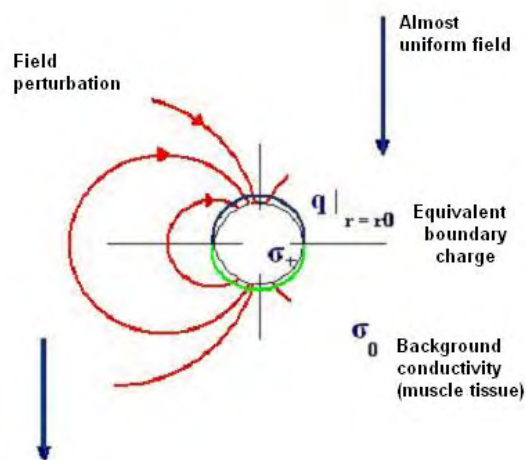

Fig 2.Conductivity unit boundary charge as resulting from electric field continuity constraint.

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It cab be shown that a small perturbation the normal component of the impressed current density is proportional to the cosine of the central angle. [8]

$$E_{n\,0}\,\sigma_0 = E_{n\,+}\,\sigma_+ \qquad (1)$$
$$(1)$$
$$E_{t\,0} = E_{t\,+} \qquad (2)$$

$$q\,|_{r\,=\,r0} = \varepsilon_0\,E_{n\,0}\,(\sigma_0/\,\sigma_+ - 1) \qquad (3)$$

$$q\,|_{r\,=\,r0} = \varepsilon_0\,J_0\,/\,\sigma_0\,(\sigma_0/\,\sigma_+ - 1)\,(\cos(\varphi)) \quad (4)$$

with, E_n and E_t are the normal and tangential electric field, σ_0 and σ_+ are the initial and perturbed conductivity, ε_0 is the electric permitivity, J_0 is the initial current density and the φ central angle of a characteristic vector to the unit circular boundary. It is important to note that the equivalent charge density *q* due to the conductivity change is a valid relation for the conductivity changes in the case of a cross section of the human arm (a factor of $n < 10$). From the charge distribution at the edge of the circular slab, in the form of a cosine function an analytical solution is known and the result is a dipole like field perturbation [7]. The cross sectional potential *V* of the induced electric field due to the perturbation can be summarized in the following formula:

$$V = A\cos(\varphi)\,/\,r^2 \qquad (5)$$

where A is a constant, r, φ are the polar co-ordinates. The constant potential lines in 2D section are not visible in a low resolution general field image as it can be seen from Fig.1. A current density simulation on a real geometry case is presented in Fig. 3 (zoom in on interest area).
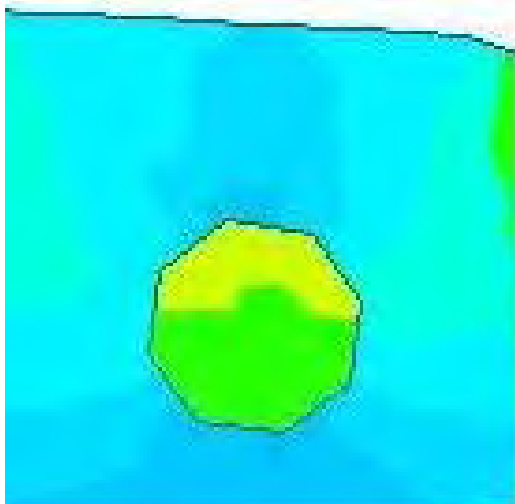
Fig 3. Induced field projection on a quasi-parallel original impressed field.

The small changes in the field are more clearly visible in this image.
Analysis of the simulated electric filed as a model of the wrist cross section reveals a number of interesting findings with practical application vectors.
The boundary potential projection of the unit area perturbation on the field in the cross section of the wrist is on the order of 2 % with pulse.
The result is obtained if the current injecting electrodes are placed in relative symmetric position to the under-laying artery. The results have been obtained using a low resolution in the triangulation of the cross section geometry. This fact was considered to be a supplemental argument that results obtained are valid even in the case of a not so regular geometrical arrangement of the conductivity zones as used for convenience.
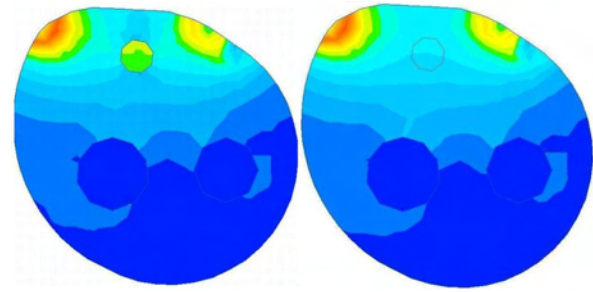
Fig 4. Induced current density field change image due to pulse in a section of the real anatomical geometry at the wrist level.

In the case of an impressed current density not very evenly parallel distributed around the artery to be imaged the simulations show that the form of the dipole field is still visible but is deformed. For the application in view this deformation is not significant since only its momentary presence is necessary for pulse detection.
The symmetry property and other form factors that can be deduced from the ideal parallel current field case are no longer valid.
Electrode placement in the proximity of the artery can be a problem in the practice. A method needs to be devised to make the determinations independent of the position of the electrodes relative to artery location.
Variability of the human subject anatomical configuration was not considered in this study even though it is clearly a limiting factor in practice.

III. FIELD CHANGES DUE TO WRIST GEOMETRY CHANGES BY HAND MOTION

Analysing the determination of an inverse image of the non homogeneity from measurements at a conductivity object boundary it is easy to observe that it admits as solution a Dirac like function. The magnitude is equal to the conductivity variation scaled by the non homogeneity area. The absolute precision in the' centre of gravity ' position is in

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evident contrast with the possible total undetermined conductivity boundary localisation.

The proof is immediate given the fact that the form of the perturbed field lines as determined for the dipole model are independent of the non homogeneity radius. The filed lines follow outside the non homogeneity area the form of a ideal dipole located at the 'centre of gravity' of the perturbation.
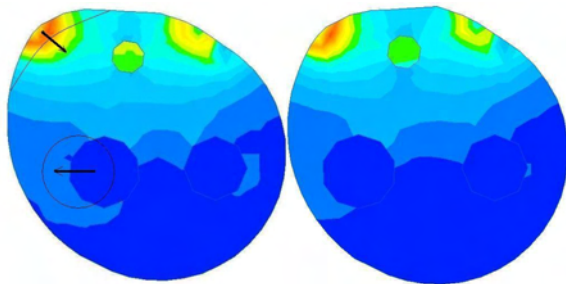

Fig 5. Induced current density field change image due to realistic anatomical geometry change due to motion at the wrist level.

The cross section of the hand in motion is continuously changing due to muscle contraction and bone displacement.

In order to simulate such geometry changes we used tow deformation of the geometry of the cross section as indicate in Fig. 5.

One bone was moved in horizontal direction and the contour of the cross section was moved in an oblique direction.

The results of the simulation at two points above the artery are summarised in Table 2.

Table 2

Boundary voltage and current density
 measurements above the artery

Case	V1	V2	J1	J2
No blood	4.4469	6.8489	0.0125	0.0110
Blood	4.2547	6.9632	0.0129	0.0113
Motion (no-blood)	4.2149	6.9005	0.0125	0.0112

The field change due to the perturbation is a result obtained for a particular initially impressed field. Additional results for other impressed values or other types of initial fields that can be decomposed in terms of parallel fields.

IV.   CONCLUSIONS

The paper presents the results of a study to determine the feasibility of the determination of pulse at the wrist using electrical impedance measurement. The cross section geometry and tissue conductivity of the hand at wrist level due to the pulsating artery are modelled by a unit regular area conductivity change. The dipole model of the electric field perturbation is found adequate by electric field simulation. The boundary voltage measurement at a location close to the artery are clearly visible both in the current density image and measurement data. The geometry changes by deformation of the shape and shifting bone position is shown to be on the same order of magnitude as the blood related changes. The inverse problem of prediction of unit area momentary conductivity changes can be estimated with ought the need for the undetermined conductivity boundary localisation. For the application in view the estimation of pulse rate can be obtained by detecting the moments of blood surging through the artery. The electric simulation data are encouraging for practical application of the method. More research is necessary to reliably separate motion artefacts from pulse data.

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