Study of Non-biological Property for Identification Cancerous Skin Tissue

Somnath Chakraborty, Debjyoti Chowdhury, and Madhurima Chattopadhyay

Abstract In this paper, an array of inter-digitated (IDT) capacitive sensors has been designed for the detection of skin malignancy on the basis of change in dielectric permittivity of human skin tissue. Here, the IDT-based capacitive sensor is designed with a pair of rectangular-shaped identical electrodes and extended for an array to facilitate such identification. The identification process is based on change in dielectric permittivity of skin tissue to presence excess water contain. In order to do so, an electrical model of skin tissue is designed to which an excitation potential of 1 V is given to study the impedance profile of skin tissue. This impedance profile is seen to be different for cancerous skin with that of a normal one. Therefore, it can discriminate a normal skin from an affected one in terms of change in impedance profile. This work is executed in multi-physics-based simulation software.

Keywords Skin malignancy · Non-biological · Simulation · Electrical model

1 Introduction

Skin cancer involves abnormal growth of skin tissue which is known as skin neoplasm (Joshi and Jadon 2012), it can be broadly classified into (i) melanoma and (ii) Non-melanoma. This abnormal growth in skin tissue can invade other portions of the human body if not detected early. Skin cancer can be caused because of prolonged exposure to UV (Ultra Violate) rays or some other form of chemical agent. Exposure to UV rays is a physical agent of skin cancer (Fabbrocini et al. 2010; Malaysia 2018; Birgersson 2012). It is estimated that the incidence of non-melanoma more than 600,000 cases each year in the United States of America and is 20% greater than the melanoma. The non-melanoma category of skin cancer has two common types namely basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) (Lu et al.

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2018; Aminzadeh et al. 2014). The BCC and SCC types of skin cancer are caused due to UV exposure which damages cell DNA directly (Schoenbach et al. 2002). The uppermost layer of the human skin is divided into four layers; stratum corneum, epidermis (E–D), dermis, and subcutis. Stratum corneum (SC) is the upper-most layer of skin which consists of corneocytes cell is highly resistive in nature and has a thickness of 0.02 mm (Kasparian et al. 2009). Epidermis the immediate next layer of skin that has thickness of 0.15 mm (Baba and Burke 2008), it comprises of Keratinocyte, Melanocytes, Langerhans, and Markel cells (Martínez and Fernando 2007). Any UV radiation that falls on a skin tissue is absorbed by melanin granules in this layer which generates heat that may sometimes cause skin cancer (Kotnik et al. 2010; Joodaki and Panzer 2018). Dermis is the next layer to epidermis and has the thickness of about 0.5 up to 2 mm (Krassowska and Filev 2007) consisting of collagen (i.e. manufactured by fibroblast cells) (Sasaki et al. 2014). It also comprises of mast cells, macrophages, sweat glands (i.e. responsible for temperature regulation of skin), hair follicles, sebaceous glands, sensory, receptors and blood vessels (Chan and Ramer 2018). Below the dermis, subcutis layer is present with comprises of Lipocytes, a fat-storing cell. Also, nerve and blood vessels are sited in this layer (Salman et al. 2012). In case of skin cancer, it is observed through literature survey, that water content in the healthy skin tissue is less than that of the malignant skin tissue. Water volume fraction of stratum corneum is 0.2, epidermis and dermis are 0.65 or 0.7. In case of skin malignancy it is approximate 0.8 (Aberg et al. 2004). Due to this difference in water content malignant skin tissue exhibits a net change in relative electrical permittivity over healthy human skin tissue, therefore, the detection of skin cancer can be done on the bases of change in electrical permittivity. Therefore, this work considers only the epidermis layer and small depth of dermis layer of skin cancer detection. The human living cell membrane, is a lipid bilayer (Corovic et al. 2013) and acts as an electrochemical gateway that allows only a certain number of ions like Na^+, K^+ etc. to pass with their concentration gradient (Arena et al. 2010a). The resistive and capacitive properties of cell membrane and its surrounding are changed due to change in frequency applied through skin tissue. By tracing the relative electrical permittivity of suspected area of skin, cancerous tissue can be detected. Impedance of cancerous cell of human skin tissue changes due to change in electrical permittivity that can be measured by applying 2 mA alternating current of frequency range of 1–100 kHz. Detection of skin cancer can be broadly classified into two different techniques of (i) self-examination, by a person and (ii) skin biopsy. Skin biopsy is an invasive method and it is most popularly used for detection skin cancer, in which a sample of skin tissue from suspected area of human body is removed and sent it to a lab for testing. This process is painful takes few days to generate results (Aberg et al. 2004). On the other hand, the two other types of non-invasive method for identification and study of malignancy in skin tissue are (I) temperature (Arena et al. 2010b) and (II) impedance profile affected tissue. By studying these non-invasive methods, it can be found that the cost of the instrument involved which is a big factor in detection of skin malignancy can be greatly reduced. The change in relative permittivity in cancerous tissue of affected area of skin can be observed at a specific frequencies in the range 1–100 kHz. Therefore, impedance profile affected tissue

method can be considered for detection of malignant skin tissue through capturing impedance values over a range of frequencies.

2 Electrical Model of Skin Tissue

The overall impedance value of skin can be evaluated using two electrical properties i.e. resistance (R) and capacitance (C) (Wang et al. 2014). Hence, in order to examine a complex frequency response a RC equivalent model of a skin tissue is developed where the resistance and capacitance represent the electrical nature the skin when subjected to frequency excitation. For evaluating this complex value of resistance (R) and capacitance (C) the standard Debye model is considered for calculation of the dielectric permittivity of a given skin tissue. For a certain frequency, the value of electrical permittivity can be evaluated with the following Debye equation, given by Eq. 1.

$$\varepsilon_r = \varepsilon_\infty + \frac{A_p(\varepsilon_s - \varepsilon_\infty)}{1 + j\omega\tau_p} + \frac{\sigma}{j\omega\varepsilon_0} \tag{1}$$

where, ε_r is relative permittivity of skin, ε_∞, ε_s are the optical permittivity and static permittivity; σ is ionic conductivity; A_p is pole amplitude with ω as angular frequency and the value of ε_0 is 8.85 pF/m, respectively. The values for the parameters are shown in Table 1. The skin impedance model can now be then classified as (i) constant phase angle model and (ii) RC layered model (Malaysia 2018).

Each layer of skin tissue consists of one type of cell or a combination of cells. These different cell types from different layers of skin tissue act as a leaky dielectric (Lu et al. 2018). As human skin tissue is anisotropic in nature, so biological and chemical properties of different layers are not similar. Therefore, a constant phase angle model does not show accurate result for evaluation of skin tissue impedance. This work, therefore, introduces R–C models for each layer of the skin tissue that the applied frequency penetrates, shown in Fig. 1. Literature study reveals that if an alternating current is applied in a suspected area on the surface of the skin, it penetrates through it and can be picked up from another point of the same surface on the skin vicinity near the point of injection. This process of excitation of skin tissue called as electroporation, the pours in the skin tissue cells are opened with

Table 1 Optimized parameters for the Debye model (Birgersson 2012)

Sr	Tissue	ε_∞	ε_s	A_p	τ_p(ps)	σ(s/m)
1	SC	3.24	4.96	1.074	2.14	0.07
2	E–D (0.67)	5	36.55	0.946	6.07	2.60
3	E–D (0.70)	5.12	37.60	1.074	6.20	2.68
4	Tumor	5.46	56.79	0.908	6.35	2.94

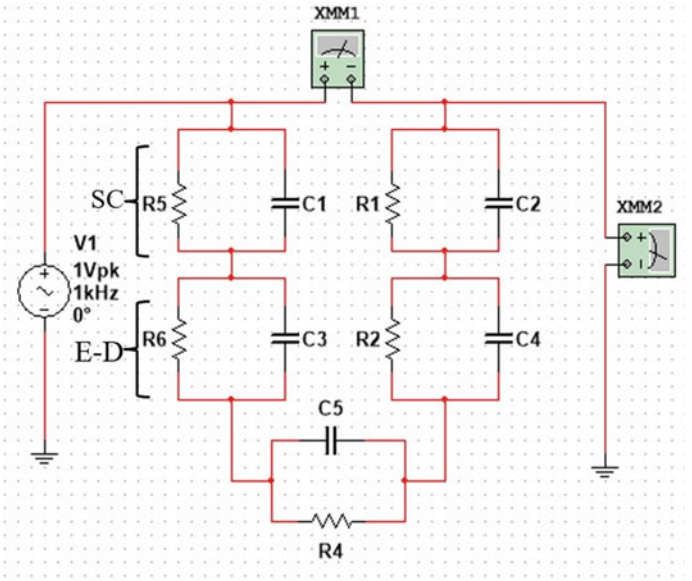

Fig. 1 Electrical circuit model of human skin tissue

a 1 V *p–p* (Lu et al. 2018) supply that causes current to flow through skin tissue. The penetration of current is proportionally depending on the gap between source electrodes (i.e., the electrode is connected with current source) and pick up electrode (i.e., the electrode where current is collected).

In this model, impedance between the electrodes and the upper surface of skin is not considered for simplicity. Therefore, an equivalent electrical circuit model of human skin tissue with different layers is designed, shown in Fig. 1.

In Fig. 1, the equivalent circuit model of skin tissue is shown; where R_1 and R_2 are the resistances of stratum corneum and combined with epidermis and dermis layers respectively. C_1 and C_2 are the capacitances of stratum corneum and combined with epidermis and dermis layers. Hence from Fig. 1, Z_1 is equivalent impedance of stratum corneum can be written as Eq. 2 and Z_2 is the combined equivalent impedance of epidermis and dermis can be written as Eq. 3.

$$Z_1 = \frac{2R_1}{1 + j\omega R_1 C_1} \tag{2}$$

$$Z_2 = \frac{3R_2}{1 + j\omega R_2 C_2} \tag{3}$$

The overall impedance of the circuit is then given by

$$Z_{\text{eq}} = Z_1 + Z_2 \tag{4}$$

Table 2 Electrical parameters of skin tissue

Sr	Layers of skin	Non-cancerous		Cancerous	
		Resistance (k Ω)	Capacitance (μF)	Resistance (k Ω)	Capacitance (μF)
1	SC	56.84	0.0028	1.35	0.1176
2	E–D	19.12	0.0083	10.69	0.0094

From Eq. 4, Z_{eq} is total impedance of this equivalent circuit model. The arithmetic values of different layers of healthy skin tissue and cancerous skin tissue are shown in Table 2 (Martínez and Fernando 2007).

The arithmetic values from the Table 2, were used to obtain a frequency relation with impedance for normal skin and cancerous skin tissue, shown in Fig. 1 (Baba and Burke 2008; Martínez and Fernando 2007; Kotnik et al. 2010). This graph renders a sharp difference between malignant skin and normal skin. The impedance value of normal skin is higher than cancerous skin in a very low frequency due to difference in water content.

3 Detection System Design

3.1 Design of the Sensor

A one-dimensional array of coplanar electrodes are designed virtually in the COMSOL Multiphysics software taking width and length of each electrode as 0.04 mm * 0.04 mm and height as 0.01 mm. The gap between two consecutive electrodes is kept as 0.02 mm and the array length as 0.46 mm (Gabriel et al. 1996). These array of electrodes, the dimension of width as 0.22 mm and length as 0.46 mm, is designed to have coplanar geometry. The starting electrode is connected to 2 mA current source and the alternative electrode is grounded, this connection pattern is repeated for each electrode pair.

The dimensions of the coplanar sensor is kept constant throughout the design so that the impedance is the function of relative permittivity of skin tissue and the applied frequency. This sensor is put on a suspected area of skin for testing of malignancy of skin. Frequency dependences Debye model is used to evaluate the di-electric values of skin tissue in different frequency ranges.

The optimized parameters values which is being shown in Table 1, are put in Debye equation to find out the relative permittivity of normal skin tissue and malignant skin tissue (Stante 2009). The Figs. 2 and 3 show the sensor design and its virtually fabricated form.

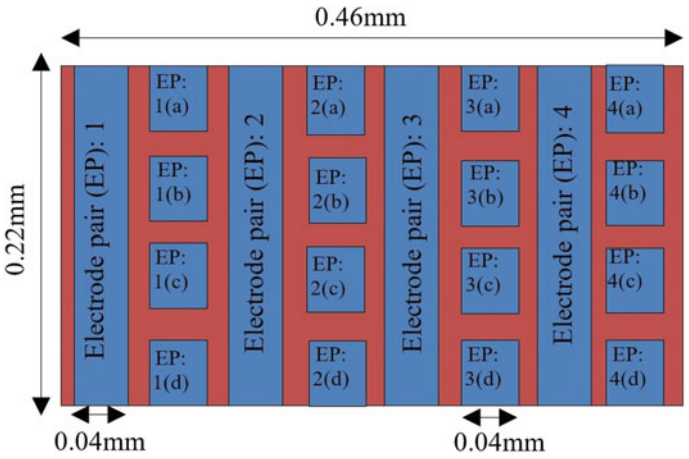

Fig. 2 Top view of the proposed sensor to study the electrical property of human skin tissue

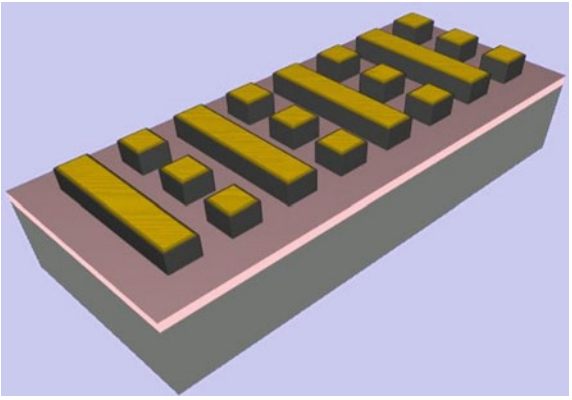

Fig. 3 Top view of the virtually fabricated sensor

3.2 Simulation of the Sensor

A range of frequency about 1 up to 100 kHz is used to detect malignancy in skin tissue. A change in electrical permittivity of skin tissue, a non-biological parameter, can change in impedance of skin tissue that can establish a difference between normal skin from cancer skin. The human skin is a complex structure with different layers, comprising with different types of cell. For their complex structure, electrical permittivity is not same for every layers of skin. Hence, it is not possible to evaluate taking equal electrical permittivity of all the layers of skin together. So to find out relative permittivity of different layers instead of taking skin as whole, Debye equation with its optimized parameters from Table 2 are introduced. The difference water content in different layers of skin produce variation in relative electrical permittivity. In case of normal skin, with combined result of different values of di-electric constant of

different layers make a gradually change in impedance with applying a frequency sweep. But in case of malignancy in skin tissue, water content in different layers of skin tissue is same. So, instead of combining effect of electrical permittivity of skin, there is an equally formed electrical permittivity caused of malignancy in skin makes gradually decreasing impedance with variation of frequencies.

4 Results and Discussion

In case of normal skin tissue layers and cancerous skin tissue, a change in electrical permittivity with the variation of applied frequency ranging from 1 to 100 kHz is found by using of Debye equation, and it is shown in Table 3. A simulation result, shown in Figs. 4 and 5, is found for cancerous skin tissue with proposed sensor using COMSOL Multiphysics software. For small change in electrical permittivity of normal skin tissue from malignant skin tissue can be isolated and detected from the graph of Figs. 4 and 5.

The change in impedance with variation of frequency reflects the alteration of di-electric values of skin tissue. Using Debye model and MATLAB software, a set of relative electrical permittivity at specific frequencies in the range of 1 to 100 kHz is found (Chattopadhyay et al. 2019; Ingole et al. 2016; Nordbotten et al. 2014).

5 Conclusion

This work based on measurement of change in electrical permittivity in skin tissue for detection of skin malignancy. The analysis of the difference of electrical permittivity of malignant skin tissue from normal skin tissue is done in COMSOL Multiphysics software and Fig. 5 is shows graphically the differences between cancerous skin tissues from normal skin tissue in terms of impedance over a range of frequencies. In the malignance of skin, water content present in the skin tissue are greater than normal skin tissue. This increase in water component changes the electrical permittivity of skin which in turn changes in impedance of skin that is identified by this proposed sensor. The Fig. 5 shows that the impedance of skin tissue is gradually decreasing with the frequency ranging from 1 to 100 kHz for non-cancerous and cancerous skin tissue. Thus, the impedance profile of an affected tissue which is a measure of change in impedance of skin as a function of electrical relative permittivity can be regarded as an alternative method of detection of skin cancer.

Table 3 Electrical parameters of skin tissue

Frequency		1 kHz	20 kHz	40 kHz	60 kHz	80 kHz	100 kHz
Sr	Skin layers	Electrical permittivity					
1	SC	1.2589E+06	6.2943E+04	3.1471E+04	2.0981E+04	1.5736E+04	1.2589E+04
2	E-D (0.65)	4.6757E+07	2.3379E+06	1.1689E+06	7.7929E+05	5.8447E+05	4.6757E+05
3	E-D (0.70)	4.8196E+07	2.4098E+06	1.2049E+06	8.0327E+05	6.0245E+05	4.8196E+05
4	Tumor	5.2872E+07	2.6436E+06	1.3218E+06	8.8120E+05	6.6090E+05	5.2872E+05

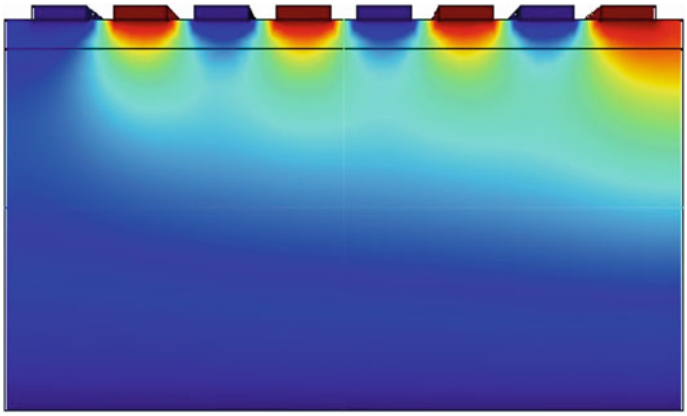

Fig. 4 Side view of simulated sensor in COMSOL multiphysics software

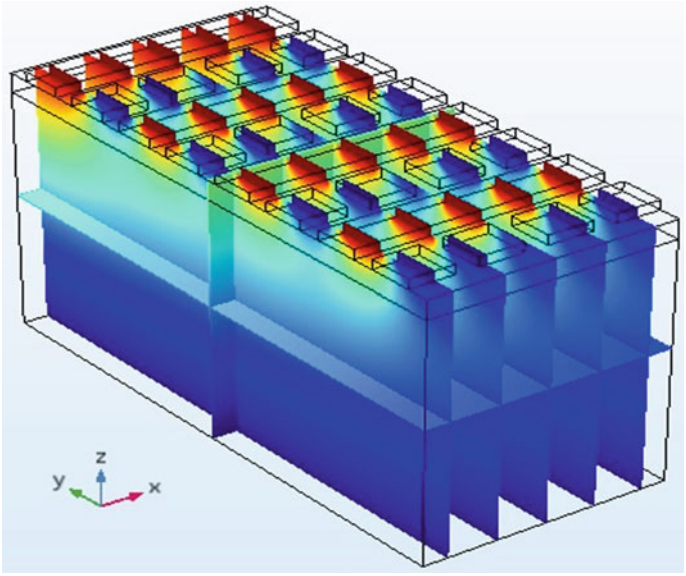

Fig. 5 The 3D view of simulated sensor in COMSOL multiphysics software

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