Conference Paper

A Novel Dermatological Diagnosis Support Device Based on Electrical Impedance Spectroscopy

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ABSTRACT

Our team has engineered a mobile and cost-efficient diagnostic tool that leverages Electrical Impedance Spectroscopy (EIS) technology to conduct differential assessment of the electrical impedance of skin tissue. Now in its third prototype iteration, the DermaSense apparatus performs non-invasive data collection from the epidermal layer, processes and analyzes the data, and serves as a support tool in dermatological diagnostic decisions. Device development focuses on an array of skin malignancies and relevant precursor conditions, such as actinic keratosis. Subsequent to rigorous evaluations in both controlled lab environments and clinical scenarios, our empirical data suggests that DermaSense holds promise in enhancing the precision of skin condition classification. Crucially, impedance measurements derived from individuals with certain pre-existing dermatological ailments appear to be distinguishable from those acquired from healthy patches of skin from the same subject, as well as those from other healthy subjects.

Keywords—*Medical devices, Dermatology, Electrical impedance spectroscopy, EIS, Actinic keratosis, Melanoma, Biomedical engineering.*

INTRODUCTION

Dermatological diseases represent a pervasive health challenge, impacting a substantial segment of the global population.[1] This encompasses a spectrum of cutaneous pathological conditions, ranging from mild afflictions such as acne and eczema to more severe diseases such as actinic keratosis and melanoma, a variant of aggressive cutaneous malignancy.[2] The diagnostic approach in dermatology is based upon an array of procedures, including visual clinical assessment, surgical excision, and histopathological evaluation.[3,4] This research delves into and introduces an EIS prototype scanner designed to augment the aforementioned conventional dermatological methodologies using novel biomarkers, potentially enhancing the precision and specificity of dermatological diagnoses, thereby facilitating prompt and effective therapeutic interventions.[5]

MATERIALS AND METHODS

Materials

Hardware

The prototype diagnostic system consists of a primary unit with a USB-2020 data acquisition mixed signal electronics board, a scanning head featuring nine spherical stainless steel electrodes (Figure 1), a signal generator to excite the skin and a microcontroller that acts as the central processing unit. A PC is utilized to run the control and visualization software.

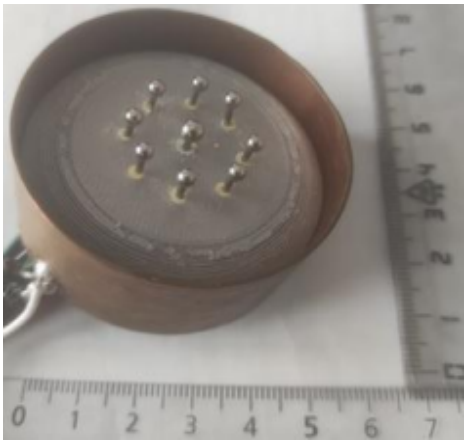

FIGURE 1. The prototype scanning head comprising of nine spherical stainless steel electrodes encased by copper.

Software

Programming has been primarily carried out using the C++ language, which generates robust and efficient executables. In addition to C++, LabVIEW is employed to provide a user-friendly interface and facilitate the visualization of data.

Experimental Setup

Human skin impedance is modeled via an electrical circuit comprising a capacitor and resistors (Figure 2). Measurements employ Ohm's law, using root mean square (RMS) values for alternating voltage and current.

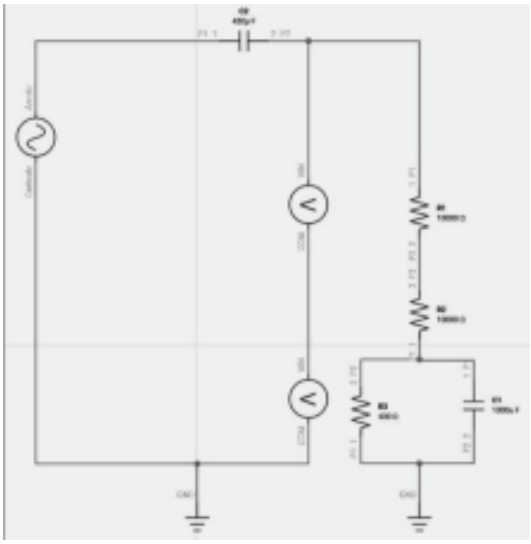

FIGURE 2. A simulation of the human impedance circuit simulated in PSPICE software.

A comprehensive characterization of electrical impedance can be achieved through an analogous electrical circuit model, as posited by.[6] However, the inherent nonlinear and time-variant attributes of the skin's electrical response necessitate a more intricate representation than a mere passive circuit. To address this, a circuit model encompassing a capacitor and two resistors in series has been proposed as an elementary yet effective framework for elucidating the intricacies of electrical impedance.[7]

To quantify the skin's impedance, one can employ the renowned Ohm's law, articulated as E = IR. For this computation, it is imperative to utilize the root mean square

(RMS) values, especially when dealing with alternating current and voltage, to ensure accuracy.

An illustrative experimental circuit, depicted in Figure 2, serves as a testament to the empirical findings derived from the scientific literature. Within this configuration, the parallel arrangement of capacitor C2 and resistor R3 is designed to compensate for the capacitive effects intrinsic to the skin. Concurrently, the series resistor, R2, provides insights into the impedance characteristics of the subcutaneous tissue layers. Notably, Resistor R1, while not directly representing any skin property, plays a reference role in the data acquisition process, facilitating the measurement of aggregate current. Furthermore, the inclusion of C1, a coupling capacitor, is of paramount importance, ensuring the segregation of AC and DC signals, thereby preserving the circuit's equilibrium state amidst the introduction of alternating currents.

Methods

Our objective was to assess the operability and applicability of the 3rd generation DermaSense prototype apparatus that we engineered. Initial trials were executed in a regulated laboratory environment, employing a tri-electrode setup (comprising power supply electrodes and a data acquisition electrode). Three experimental sets were undertaken, with electrodes consistently positioned within an identical skin region on a participant's forearm, modulating electrode distances from 150 mm to 450 mm. To discern the influence of electrode categorization on the acquired signals, two discrete electrode variants, specifically adhesive ECG electrodes and spherical stainless steel electrodes, were utilized, and their resultant data were compared.

Upon corroborating the operability of the prototype device, clinical measurements were procured from three male subjects, each suffering from various dermatological pathologies across diverse cutaneous areas of the skin. These assessments were orchestrated under the aegis of a dermatologist at the 2nd Department of Dermatology-Venereology inside the Dermatological Clinic of Papageorgiou Hospital. Among the two electrode categories chosen for this investigation, adhesive ECG electrodes were deemed inappropriate due to their expansive contact surface area with the epidermis, obstructing the establishment of an electrode matrix conducive to comparative differential evaluations.

RESULTS

In this study, two types of electrodes were evaluated. The adhesive ECG electrodes were deemed inappropriate for the intended purpose. Their unsuitability arises from even the smallest ones having a significant skin contact surface area, which hinders the formation of an electrode array for comparative differential readings. Our experimental regimen subjected three healthy individuals to a consistent voltage (approximately 1.68 V) across escalating frequencies (spanning from 100 Hz to 14 kHz). Data retrieval outcomes were replicable and congruent with simulation findings, affirming the operability of the prototype apparatus. Initial clinical trials encompassed measurements from both healthy and pathological skin of three male subjects of varied ages. Each participant exhibited specific dermatological pathologies, as verified by a clinical evaluation executed by a dermatologist prior to data acquisition with the DermaSense prototype apparatus.

The first patient, aged 71, presented multiple suspicious lesions dispersed across facial regions and other cranial areas, with a singular lesion being quantifiable due to the restrictive geometric design of the prototype scanner. The subsequent patient, aged 50, presented with potential malignant lesions on the posterior aspect of his left foot sole; EIS measurements were procured using the prototype apparatus upon the dermatologist's directive. The tertiary patient, aged 63, was diagnosed with pronounced actinic keratosis on both forearms.

Notably, the measurement locale of this patient's skin was especially apt, aligning with the region employed in the preliminary validation trials, facilitating a robust comparison against an expansive dataset previously gathered. Remarkably, data derived from the trio of patients unveiled significant findings, particularly pertaining to the third patient (Figures 3 and 4), whose measurements exhibited a pronounced deviation from the consistent pattern observed in the results of healthy participants (Figure 5).

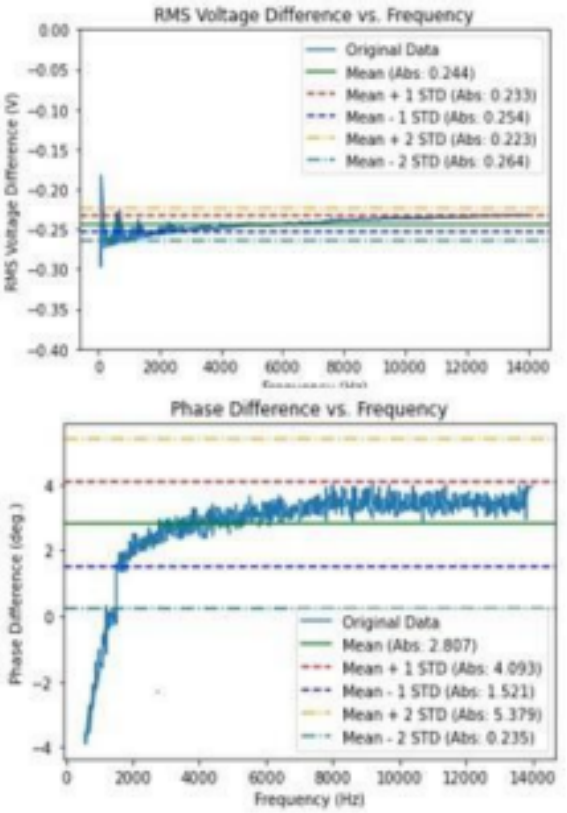

FIGURE 3. Measurements taken from the left forearms of a healthy male subject aged 27 (top) and a male patient aged 63 presenting actinic keratosis (bottom).

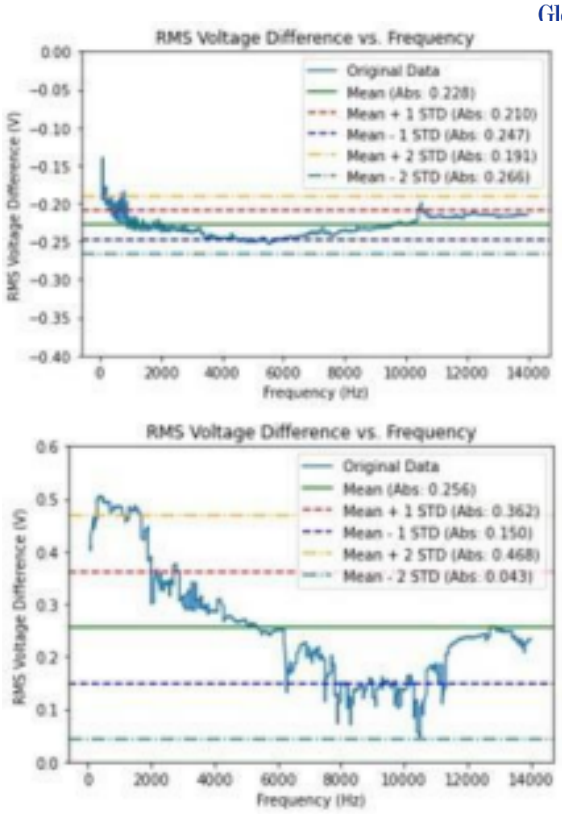

FIGURE 4. Phase differences of measurements obtained from the left forearms of a healthy male subject aged 27 (top) and a male patient aged 71 presenting actinic keratosis (bottom).

The RMS voltage values of the measurements typically ranged from −1 standard deviation (STD) to +1 STD. However, for the third patient, the measurements deviated more significantly, spanning beyond ±2 STD. Additionally, the phase difference measurements were not distinct enough to draw any definitive conclusions or assumptions.

DISCUSSION

The newly developed DermaSense system holds promise for assisting non-invasive and accurate diagnoses of various skin conditions, although it remains a work-in progress. To optimize the scanner's functionality, forthcoming iterations will feature modular heads, engineered to conform to the topographical intricacies of skin surfaces.[8] Furthermore, the database will undergo augmentation to encompass a broader demographic, thereby enhancing the comprehensiveness and fidelity of the reference dataset. The integration of advanced machine learning algorithms is projected to fine-tune data categorization, thereby amplifying the system's diagnostic precision and robustness.[9,10] Progressive enhancements in scanner technology, data procurement methodologies, and artificial intelligence competencies are expected to perpetually refine the DermaSense apparatus, priming it for standard clinical deployment.

CONCLUSION

The laboratory outcomes validate the prototype DermaSense device's performance when using stainless steel electrodes compared to adhesive ECG electrodes, as indicated by the statistical analysis. Additionally, time series analyses showed minimal signal variations, implying stable data capture under changing conditions. Meanwhile, the clinical findings supported the device's

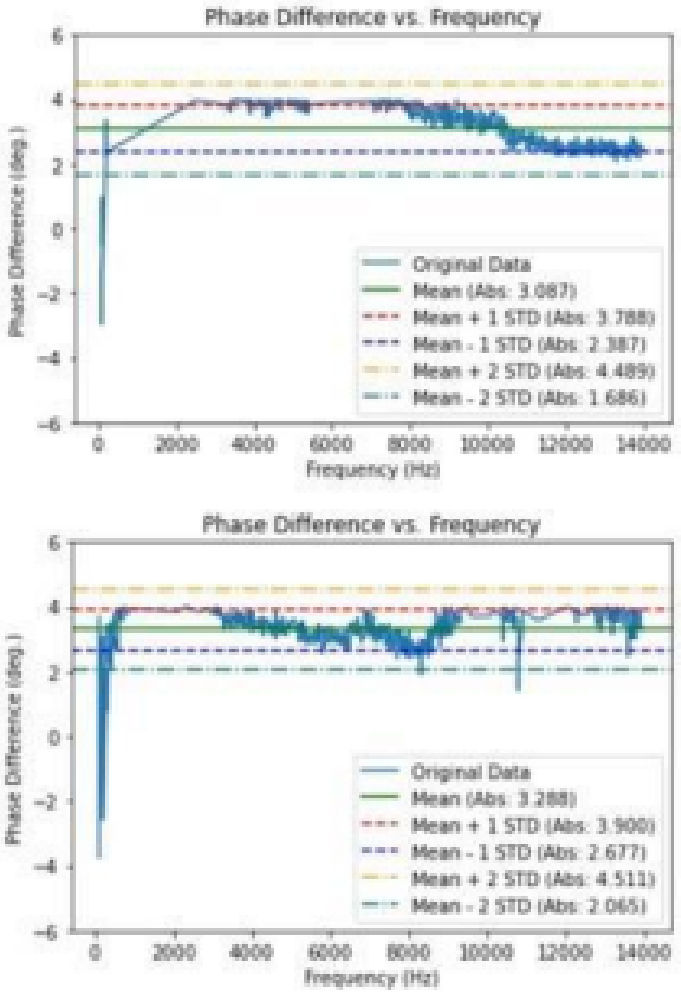

FIGURE 5. Measurements taken from the left forearm of a healthy male subject aged 30.

effectiveness, as the impedance measurements from patients with dermatological issues significantly differed from those of healthy individuals. Furthermore, dermatologists confirmed the utility of the device in assisting with diagnostic decisions, particularly in complicated cases involving various skin conditions.

In light of the research presented, the DermaSense system appears to be a promising support tool for traditional dermatological diagnostic methods. The third generation of this prototype device has demonstrated its capability to non-invasively and more accurately assess the electrical impedance of the epidermal layer, offering promising insights into the electrical characteristics of skin tissue. Our experimental findings, both from controlled laboratory settings and real-world clinical scenarios, underscore the device's improved efficacy, especially when utilizing stainless steel electrodes.

The significant deviations in impedance measurements between patients with dermatological pathologies and healthy subjects further bolster the device's potential to enhance the specificity and accuracy of skin condition classification. Moreover, the positive feedback from dermatologists accentuates the DermaSense apparatus's potential role in aiding diagnostic decisions, especially in intricate cases with multiple skin conditions.

In summary, the DermaSense apparatus, with its innovative use of EIS, stands poised to revolutionize dermatological diagnostics, offering a cost-effective, mobile, and precise tool that could potentially expedite and enhance therapeutic interventions for a myriad of skin pathologies. Future endeavors should focus on refining the device's design for broader applicability and further validating its efficacy across a more diverse patient demographic.[11]

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