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(54) **ULTRASOUND IMAGING USING A NULL SUBTRACTION IMAGING TECHNIQUE**

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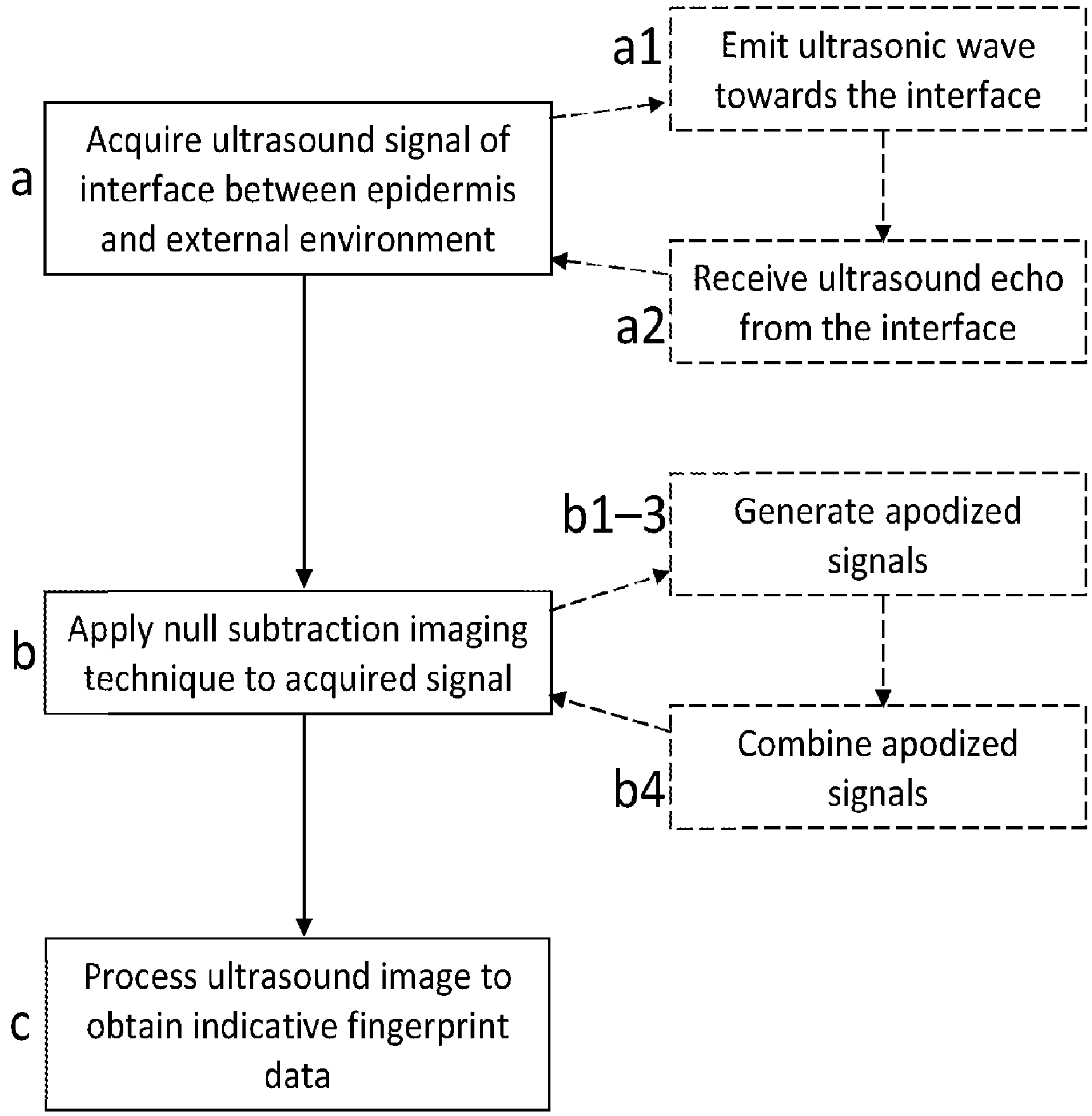
(57) **ABSTRACT**

In a first aspect, the present disclosure relates to a method for visualizing an interface between an epidermis and an external environment. The method comprises: (a) acquiring an ultrasound signal of the interface using an ultrasonic transducer array; and (b) applying a null subtraction imaging technique to the acquired ultrasound signal, thereby forming an ultrasound image.



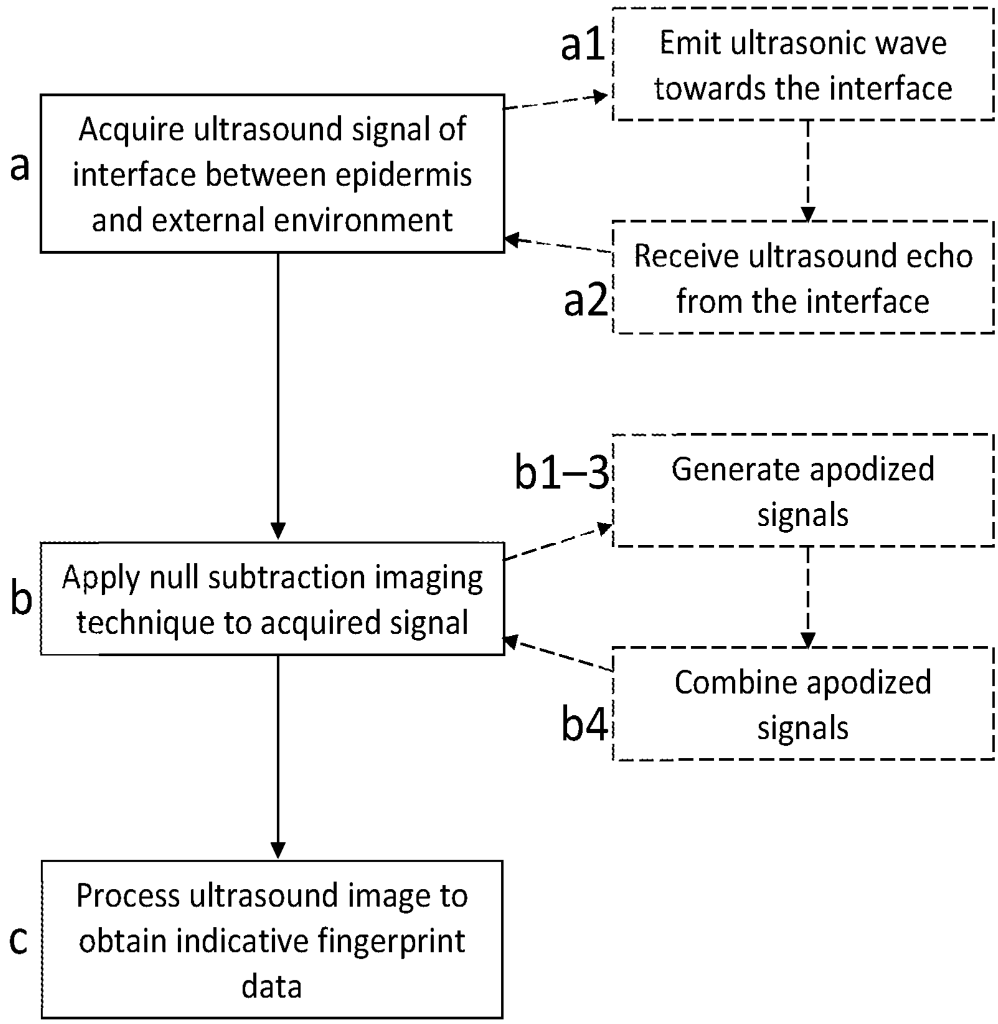

a
Acquire ultrasound signal of interface between epidermis and external environment
a1
Emit ultrasonic wave towards the interface
a2
Receive ultrasound echo from the interface
b1–3
Generate apodized signals
b
Apply null subtraction imaging technique to acquired signal
b4
Combine apodized signals
c
Process ultrasound image to obtain indicative fingerprint data

FIG. 1

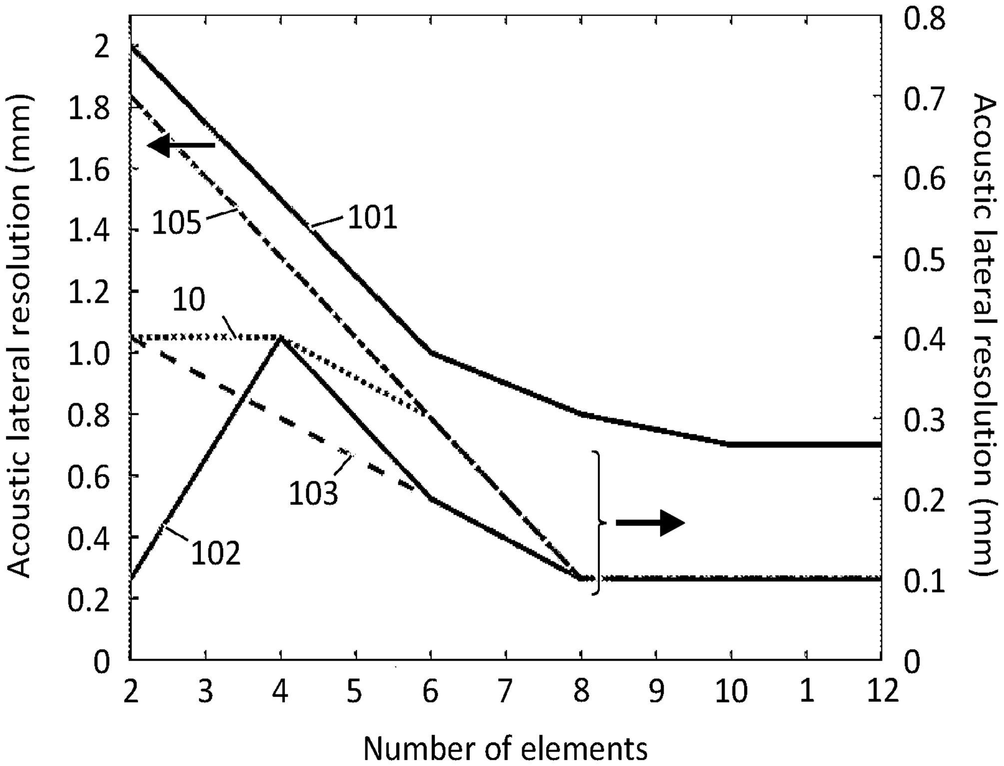

Acoustic lateral resolution (mm)
2
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
105
101
10
103
102
2
3
4
5
6
7
8
9
10
1
12
Number of elements
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Acoustic lateral resolution (mm)

FIG. 2

ULTRASOUND IMAGING USING A NULL SUBTRACTION IMAGING TECHNIQUE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a non-provisional patent application claiming priority to European Patent Application No. 18202321.8, filed Oct. 24, 2018, the contents of which are hereby incorporated by reference.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to ultrasound imaging of an interface between an epidermis and an external environment and particularly to signal processing techniques used for the ultrasound imaging.

BACKGROUND

[0003] Fingerprint imaging requires a high resolution (e.g. 100 μm or better) in order to visualize fingerprint features with sufficient accuracy to guarantee a reliable recognition. Ultrasound imaging is a very interesting and promising technology for fingerprint imaging, offering a robust imaging (e.g. being less susceptive than capacitive sensors to contamination and moisture on the finger) and enabling a high level of security. An easy, cheap, robust and reliable fingerprint imaging is for example useful in view of securing the access to an increasing number of items, such personal electronic devices (e.g. phone, tablet, watch, laptop, or PC), personal data (e.g. bank, work, social security, and health data), doors, luggage, etc.

[0004] However, using signal processing techniques which are commonly used up to now (e.g. standard linear beamforming), a high ultrasound frequency must be used to achieve a high spatial resolution. Indeed, the fundamental physical limit for resolution is normally dictated by diffraction. For a rectangular aperture with lateral size L, the theoretical −12 dB lateral spatial resolution L_r can be evaluated using the formula

$$L_r = 1.6\frac{cz}{Lf_0},$$

wherein c is the speed of sound, z is the depth and f_0 is the center frequency of the transmitted pulse (c.f. Demi, Libertario, et al. "Implementation of parallel transmit beamforming using orthogonal frequency division multiplexing-achievable resolution and interbeam interference." *IEEE transactions on ultrasonics, ferroelectrics, and frequency control* 60.11 (2013): 2310-2320). As such, to achieve a resolution of at least 100 μm, frequencies of about 20 MHz or higher are required for a speed of sound of 5600 m/s (e.g. glass), an imaging depth of 1 mm and a lateral aperture size of 5 mm. This puts stringent requirements on the transmitting and receiving electronics, and on the aperture size (e.g. on the total number of ultrasonic transducer elements in an ultrasonic transducer array). Additionally, standard beamforming requires the ability to accurately control the phase of the signals used to drive each transducer element, with an accuracy in the order or higher than a tenth of the wavelength. However, this is increasingly difficult to achieve with increasing driving frequencies. Moreover, since attenuation of a sound wave is a frequency dependent phenomenon, where attenuation increases with frequency, using high frequencies has a negative impact on the propagation of the ultrasound wave. The signal-to-noise ratio and achievable imaging depths therefore deteriorate for higher frequencies.

[0005] There is therefore a need in the art for better methods for ultrasound imaging, e.g. for fingerprint imaging, particularly ones which would allow for lower ultrasound frequencies to be used for a given aperture size (e.g. the total number of ultrasonic transducer elements in an ultrasonic transducer array) while maintaining a high resolution.

SUMMARY

[0006] It is an object of the present disclosure to provide good methods and associated products for visualizing an interface between an epidermis and an external environment. This objective is accomplished by methods, products and a use according to the present disclosure.

[0007] In a first aspect, the present disclosure relates to a method for visualizing an interface between an epidermis and an external environment. The method comprises: (a) acquiring an ultrasound signal of the interface using an ultrasonic transducer array; and (b) applying a null subtraction imaging technique to the acquired ultrasound signal, thereby forming an ultrasound image.

[0008] Various embodiments of the present disclosure provide that a high-resolution visualization can still be achieved at relatively low ultrasound frequencies. Keeping other factors the same, an improved in the resolution by a factor 5 or more, such as a factor of 8 or 20 or more, compared to standard linear beamforming could for instance be achieved. It is a further advantage of embodiments of the present disclosure that a super-resolution visualization can be made, i.e. that a resolution going beyond the boundary set by the traditional diffraction limit can be achieved.

[0009] Some embodiments of the present disclosure provide that, for a given resolution, comparatively lower ultrasound frequencies can be used than those used in the methods of the known art (e.g. standard linear beamforming). Furthermore, various embodiments of the present disclosure provide that the impact of attenuation can be reduced by the use of lower ultrasound frequencies, leading to an improved signal-to-noise ratio and an improved image depth.

[0010] Various embodiments of the present disclosure provide that the visualization of the interface can be achieved with high contrast.

[0011] Example embodiments of the present disclosure provide that the method is robust against contamination and/or moisture on the interface.

[0012] Some embodiments of the present disclosure provide that there may be no need, or a reduced need, for controlling the phase of the ultrasound hardware driving signals (e.g. for performing plane wave compounding with different steering angels) and for focusing of either or both of the emitted ultrasound wave and the received ultrasound echo, with the aim to further improve spatial resolution.

[0013] In embodiments, acquiring an ultrasound signal of the interface may comprise the substeps of: (a**1**) emitting an ultrasonic wave towards the interface; and (a**2**) receiving an ultrasound echo from the interface, thereby obtaining the ultrasound signal.

[0014] In embodiments, applying the null subtraction imaging technique may comprise the substeps of: (b**1**) applying a first apodization weight to the acquired ultrasound signal, thereby generating a first apodized signal; (b2) applying a second apodization weight to the acquired ultrasound signal, thereby generating a second apodized signal; (b3) applying a third apodization weight to the acquired ultrasound signal, thereby generating a third apodized signal; and (b4) combining the first, second and third apodized signals to form the ultrasound image.

[0015] Some embodiments of the present disclosure provide that the null subtraction imaging technique may be based on three or more apodized signals.

[0016] In embodiments, the ultrasonic transducer array may comprise a transducer array aperture, and the first apodization weight may have a zero mean value across the transducer array aperture and the second and third apodization weights may have a non-zero mean value across the transducer array aperture.

[0017] In embodiments, the second apodization weight may be obtained by adding a DC bias to the first apodization weight and the third apodization weight may be a transpose of the second apodization weight.

[0018] In embodiments, combining the first, second and third apodized signals may comprise making a linear combination of the first, second and third apodized signals.

[0019] It is an advantage of embodiments of the present disclosure that the method may be performed in a relatively straightforward and economic fashion.

[0020] In a second aspect, the present disclosure relates to a method for scanning a fingerprint. The method comprises the method for visualizing an interface (e.g. of a finger) between an epidermis and an external environment according to an embodiment of the first aspect and further comprises a step c of: (c) processing the ultrasound image to obtain data indicative of the fingerprint.

[0021] Some embodiments of the present disclosure provide that a fingerprint can be scanned and that corresponding indicative fingerprint data can be generated, e.g. for storage of the scanned fingerprint and/or for comparison to other fingerprint data.

[0022] In a third aspect, the present disclosure relates to a device adapted to carry out the steps of the method according to an embodiment of the first or second aspect.

[0023] Various embodiments of the present disclosure provide that the requirements on the transmitting and receiving hardware (e.g. receiver, transmitter and/or associated elements, such as electronics) and on the aperture size (e.g. the size of the transducer array), can be relaxed; for example, because the ultrasound frequency can be relatively low and/or because there may be no need for phase control and/or focusing. It is a further advantage of embodiments of the present disclosure that this can result in devices of smaller dimensions, which is for example useful in mobile applications (e.g. mobile phones) where the available space is highly limited.

[0024] Various embodiments of the present disclosure provide that, if a corresponding adaptation of their ultrasound signal processing is foreseen, at least some of the presently known ultrasound imaging devices (e.g. at least some of the known ultrasound fingerprint scanners) could be used for performing the method. Additionally, some embodiments of the present disclosure provide that such an adaption could be substantially achieved in some systems through a software implementation, e.g. without necessarily requiring a complete redesign of the hardware (e.g. particularly the ultrasound hardware).

[0025] In embodiments, the device may comprise an ultrasound detector.

[0026] In embodiments, the device may comprise an ultrasound emitter.

[0027] Various embodiments of the present disclosure provide that either a distinct ultrasonic receiver or an ultrasonic transmitter can be used, or that a combined ultrasonic transceiver can be used.

[0028] In embodiments, the device may be a fingerprint scanner.

[0029] In a fourth aspect, the present disclosure relates to a computer program product comprising instructions which, when the program is executed on a computer, cause the computer to carry out the steps of the method according to an embodiment of the first or second aspect.

[0030] In a fifth aspect, the present disclosure relates to a computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the steps of the method according to an embodiment of the first or second aspect.

[0031] In a sixth aspect, the present disclosure relates to a use of ultrasound imaging for visualizing an interface between an epidermis and an external environment, wherein the ultrasound imaging uses a null subtraction imaging technique.

[0032] In embodiments, the use may be for visualizing a fingerprint.

[0033] In a seventh aspect, the disclosure relates to a device configured or adapted to carry out the steps of the method according to an embodiment of the sixth aspect.

[0034] Particular aspects of the disclosure are set out in the accompanying independent and dependent claims. Features from the dependent claims may be combined with features of the independent claims and with features of other dependent claims as appropriate and not merely as explicitly set out in the claims.

[0035] Although there has been constant improvement, change and evolution of devices in this field, the present concepts are believed to represent substantial new and novel improvements, including departures from prior practices, resulting in the provision of more efficient, stable and reliable devices of this nature.

[0036] The above and other characteristics, features and certain aspects of the present disclosure will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the disclosure. This description is given for the sake of example only, without limiting the scope of the disclosure. The reference figures quoted below refer to the attached drawings.

BRIEF DESCRIPTION OF THE FIGURES

[0037] The above, as well as additional, features will be better understood through the following illustrative and non-limiting detailed description of example embodiments, with reference to the appended drawings.

[0038] FIG. **1** is a flow-chart in accordance with example embodiments of the present disclosure.

[0039] FIG. **2** shows experimentally obtained acoustic lateral resolutions in function of the number of elements used in an ultrasonic transducer array, for different processing techniques and processing parameters in accordance with example embodiments of the present disclosure.

[0040] In the different figures, the same reference signs refer to the same or analogous elements. All the figures are schematic, not necessarily to scale, and generally only show parts which are necessary to elucidate example embodiments, wherein other parts may be omitted or merely suggested.

DETAILED DESCRIPTION

[0041] Example embodiments will now be described more fully hereinafter with reference to the accompanying drawings. That which is encompassed by the claims may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example. Furthermore, like numbers refer to the same or similar elements or components throughout. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. The dimensions and the relative dimensions do not necessarily correspond to actual reductions to practice of the disclosure.

[0042] The terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the disclosure described herein are capable of operation in other sequences than described or illustrated herein.

[0043] Moreover, the terms top, under and the like in the description and the claims are used for descriptive purposes and not necessarily for describing relative positions. It is to be understood that the terms so used are interchangeable with their antonyms under appropriate circumstances and that the embodiments of the disclosure described herein are capable of operation in other orientations than described or illustrated herein.

[0044] It is to be noticed that the term "comprising", used in the claims, should not be interpreted as being restricted to the means listed thereafter; it does not exclude other elements or steps. It is thus to be interpreted as specifying the presence of the stated features, integers, steps or components as referred to, but does not preclude the presence or addition of one or more other features, integers, steps or components, or groups thereof. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present disclosure, relevant components of the device are A and B.

[0045] Similarly, it is to be noticed that the term "coupled", also used in the claims, should not be interpreted as being restricted to direct connections only. The terms "coupled" and "connected", along with their derivatives, may be used. It should be understood that these terms are not intended as synonyms for each other. Thus, the scope of the expression "a device A coupled to a device B" should not be limited to devices or systems wherein an output of device A is directly connected to an input of device B. It means that there exists a path between an output of A and an input of B which may be a path including other devices or means. "Coupled" may mean that two or more elements are either in direct physical or electrical contact, or that two or more elements are not in direct contact with each other but yet still co-operate or interact with each other.

[0046] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present disclosure. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0047] Similarly, it should be appreciated that in the description of exemplary embodiments of the disclosure, various features of the disclosure are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed disclosure requires more features than are expressly recited in each claim. Rather, as the following claims reflect, claimed features lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this disclosure.

[0048] Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the disclosure, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

[0049] Furthermore, some of the embodiments are described herein as a method or combination of elements of a method that can be implemented by a processor of a computer system or by other means of carrying out the function. Thus, a processor with the necessary instructions for carrying out such a method or element of a method forms a means for carrying out the method or element of a method. Furthermore, an element described herein of an apparatus embodiment is an example of a means for carrying out the function performed by the element for the purpose of carrying out the disclosure.

[0050] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the disclosure may be practised without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

[0051] The following terms are provided solely to aid in the understanding of the disclosure.

[0052] As used herein, and unless otherwise specified, an epidermis is the outermost layer of skin of a body part of a human or another animal (e.g. a vertebrate animal), or the outermost skin cell layer of a plant part.

[0053] As used herein, and unless otherwise specified, an ultrasonic transducer array is an array of a plurality of ultrasonic transducer elements. In embodiments, the ultrasonic transducer may be an ultrasonic receiver, an ultrasonic transmitter or an ultrasonic transceiver.

[0054] In a first aspect, the present disclosure relates to a method for visualizing an interface between an epidermis and an external environment. The method comprises: (a) acquiring an ultrasound signal of the interface using an ultrasonic transducer array; and (b) applying a null subtraction imaging technique to the acquired ultrasound signal, thereby forming an ultrasound image. These steps are schematically depicted as steps a and b in the flow-chart of FIG. **1**.

[0055] In embodiments, the epidermis may be an epidermis of a human or animal body part. In some embodiments, the body part may be a finger or a portion of a finger (e.g. a top portion of a finger, such as a fingertip). In embodiments, the interface that is visualized may correspond to a fingerprint.

[0056] In embodiments, the external environment may comprise a fluid. In embodiments, the fluid may be a gas (e.g. air, such as ambient air) and/or a liquid (e.g. a liquid with a high acoustical impedance mismatch with respect to the epidermis). For example, the epidermis may be in contact with the gas, or may be submerged in the liquid, or may have a layer or droplets of the liquid thereon (e.g. as in the case of a wet or moist body part, such as a wet or moist finger).

[0057] In embodiments, the ultrasonic transducer array may comprise 2 or more ultrasonic transducer elements, in some embodiments from 2 to 20, in some embodiments from 4 to 12, and in some embodiments from 6 to 10, such as 8 or more ultrasonic transducer elements. In embodiments, the ultrasonic transducer array (e.g. ultrasonic emitter and/or receiver) may operate at an ultrasound frequency of from 1 to 50 MHz, in some embodiments from 5 to 20 MHz, such as from 10 to 15 MHz.

[0058] In embodiments, acquiring an ultrasound signal of the interface may comprise the substeps of: (a**1**) emitting an ultrasonic wave towards the interface; and (a**2**) receiving an ultrasound echo from the interface, thereby obtaining the ultrasound signal. These steps are schematically depicted as steps a**1** and a**2** in the flow-chart of FIG. **1**. In embodiments, emitting an ultrasonic wave may comprise using an ultrasound emitter (e.g. an ultrasound transmitter or an ultrasound transceiver). In embodiments, receiving the ultrasound echo may comprise using an ultrasound detector (e.g. an ultrasound receiver or an ultrasound transceiver). In embodiments, the ultrasound emitter may be a first ultrasonic transducer array and/or the ultrasound receiver may be a second ultrasonic transducer array. In embodiments, the first ultrasonic transducer array and the second ultrasonic transducer array may be a same ultrasonic transducer array or may be two different ultrasonic transducer arrays. In embodiments in which the first ultrasonic transducer array and the second ultrasonic transducer array are the same ultrasonic transducer array, the array may be the ultrasonic transducer array referred to in step (a). In embodiments in which the first ultrasonic transducer array and the second ultrasonic transducer array are different ultrasonic transducer arrays, either of the first ultrasonic transducer array or the second ultrasonic transducer array may be the ultrasonic transducer array referred to in step a.

[0059] The use of the null subtraction imaging technique is known in the field of (bio)medical ultrasound imaging, for example from Reeg (2016) (Reeg, Jonathan R. *Null subtraction imaging technique for biomedical ultrasound imaging*. 2016. PhD Thesis). The field of (bio)medical ultrasound imaging deals with ultrasound imaging of the interior of a human or animal body, aiming to visualize internal tissues, nerves, veins, muscles, tumours, cellular structures, etc. However, a disadvantage of null subtraction imaging signal processing technique is that, while the resolution of the constructed image is improved, the contrast thereof decreases. This trade-off is not always worthwhile and, consequently, Reeg (2016) states: "For contrast targets, a decrease in CNR [i.e. contrast-to-noise ratio] was observed that could not fully be compensated for. This makes our imaging technique ideal for the detection of small, highly reflective targets, but not a one-size-fits-all approach for all ultrasound imaging tasks." (Reeg, 2016, p. 35).

[0060] However, it was surprisingly realized within the present disclosure that imaging of the epidermis for e.g. fingerprint scanning is in fact not an imaging of the epidermal tissue as such, but a visualization of the interface between the epidermis and the outside environment. This leads to a number of considerably distinct conditions for this type of imaging, which are not typically found in (bio) medical ultrasound imaging; thereby setting itself apart from that field. First, whereas different tissues and structures inside the body are typically characterized by relatively small acoustic impedance differences, there is a high acoustical impedance mismatch between the epidermis and the outside environment (e.g. air). Second, whereas the interior of the body comprises a large number of different structures and tissues, the visualization of the epidermal interface corresponds to the visualization of a binary object: the epidermal tissue (e.g. ridges in a fingerprint) and the outside environment (e.g. valleys in a fingerprint that are filled with air). Third, whereas the interior of the body typically has structures ranging in size from several tens of cm to as low as a few nm and typically comprises a dense concentration of randomly oriented scatterers, the features (e.g. ridges and valleys) to be visualized of the epidermal interface have sizes which are compatible with the targeted spatial resolution (e.g. in the order of 100 μm) and typically have a more organized orientation. Fourth, the visualization of the epidermal interface may typically require only one (or two) imaging planes to be measured; furthermore, these imaging planes are typically at a fixed depth which is known a priori. As such, it was for the first time recognized that null subtraction imaging can be particularly advantageously used in the ultrasound imaging of the epidermal interface, thereby improving the resolution of the obtained image without being overly negatively impacted by the loss of contrast. In this context, it is worth noting that the epidermal interface is not a 'small, highly reflective target' and this is therefore indeed not an application which was anticipated by Reeg (2016).

[0061] In embodiments, applying the null subtraction imaging technique may comprise the substeps of: separately applying two or more apodization weights to the acquired ultrasound signal, thereby generating two or more apodized signals and subsequently combining the two or more apodized signals to form the ultrasound image. In embodiments, the ultrasonic transducer array may comprise a transducer array aperture, and at least one of the apodization weights may have a zero mean value across the transducer array aperture, while at least one other of the two or more apodization weights may have a non-zero mean value across the transducer array aperture. In embodiments, combining the two or more apodized signals may comprise making a linear combination of the two or more apodized signals.

[0062] In some embodiments, applying the null subtraction imaging technique may be performed by the 'bridging approach'; cf. Reeg (2016, p. 7-9, chapter 3.2), which is incorporated herein by reference. In embodiments, applying the null subtraction imaging technique may comprise the substeps of: (b**1**) applying a first apodization weight to the acquired ultrasound signal, thereby generating a first apodized signal; (b**2**) applying a second apodization weight to the acquired ultrasound signal, thereby generating a second apodized signal; (b**3**) applying a third apodization weight to the acquired ultrasound signal, thereby generating a third apodized signal; and (b**4**) combining the first, second and third apodized signals to form the ultrasound image. These steps are schematically depicted as steps b**1**-**3** and b**4** in the flow-chart of FIG. **1**. In embodiments, the ultrasonic transducer array may comprise a transducer array aperture, and the first apodization weight may have a zero mean value across the transducer array aperture and the second and third apodization weights may have a non-zero mean value across the transducer array aperture. In embodiments, the second apodization weight may be obtained by adding a DC bias to the first apodization weight and the third apodization weight may be a transpose of the second apodization weight. In embodiments, combining the first, second and third apodized signals may comprise making a linear combination of the first, second and third apodized signals. In embodiments, the linear combination may comprise subtracting the first apodized signal from a sum of the second and third apodized signals.

[0063] In other embodiments, applying the null subtraction imaging technique may be performed by the 'masking approach'; cf. Reeg (2016, p. 7, chapter 3.1), which is incorporated herein by reference. In embodiments, applying the null subtraction imaging technique may comprise the substeps of: (b**1**) applying a first apodization weight to the acquired ultrasound signal, thereby generating a first apodized signal; (b**2**) applying a second apodization weight to the acquired ultrasound signal, thereby generating a second apodized signal; and (b**4**) combining the first and second apodized signals to form the ultrasound image. In embodiments, the ultrasonic transducer array may comprise a transducer array aperture, and the first apodization weight may have a zero mean value across the transducer array aperture and the second apodization weights may have a non-zero mean value across the transducer array aperture. In embodiments, the two main lobes of the first apodized signal may be such that they mask the main lobe of the second apodized signal. In embodiments, the second apodization weight may correspond to a rectangular apodization. In embodiments, the first apodization weight may correspond to a single-square wave cycle apodization. In embodiments, combining the first and second apodized signals may comprise making a linear combination of the first and second apodized signals. In embodiments, the linear combination may comprise scaling the second apodized signal and subsequently subtracting the first apodized signal therefrom.

[0064] In other embodiments, applying the null subtraction imaging technique may be performed by yet another approach.

[0065] In embodiments, the method may further be for visualizing a layer beyond the interface (e.g. for visualizing the epidermis or the dermis). Visualizing beyond the interface can advantageously allow determining, for example, the pulsatility in the target (e.g. in the fingertip). This can allow a further level of security, e.g. in fingerprint scanning, because it can allow verifying that what is being imaged is indeed the epidermal interface of a living being and not a replica thereof. Because the method for visualizing the epidermal interface in accordance with embodiments of the present disclosure can operate at lower ultrasound frequencies, a lower attenuation and deeper penetration of the ultrasound waves can advantageously be achieved. If the loss of contrast by using null subtraction imaging for the deeper layer becomes too predominant, it can be considered to combine null subtraction imaging for the high-resolution visualization of the epidermal interface and standard linear beamforming (or another technique) for the higher contrast (but at the cost of a loss of resolution) visualization of the deeper layer.

[0066] In embodiments, any feature of the first aspect or its embodiments may independently be as correspondingly described for embodiments of any other aspect.

[0067] In a second aspect, the present disclosure relates to a method for scanning a fingerprint. The method comprises the method for visualizing an interface (e.g. of a finger) between an epidermis and an external environment according to an embodiment of the first aspect and further comprises a step c of: (c) processing the ultrasound image to obtain data indicative of the fingerprint (e.g. to obtain a digital fingerprint pattern, to obtain a string representative of the fingerprint, etc.). This step is schematically depicted as steps c in the flow-chart of FIG. **1**.

[0068] In embodiments, the data indicative of the fingerprint may be suitable for comparing the scanned fingerprint to one or more known fingerprints, which may for example also be in the form of corresponding indicative fingerprint data. The known fingerprints data may, for example, have been obtained from a previous scan and/or may be retrieved from a database. Various algorithms are known in the art for processing an image of a fingerprint (e.g. the ultrasound image; cf. step c) on the one hand, and for comparing (which can also be referred to as 'matching') indicative fingerprint data on the other hand; as such, these are not further discussed here.

[0069] In embodiments, any feature of the second aspect or its embodiments may independently be as correspondingly described for embodiments of any other aspect.

[0070] In a third aspect, the present disclosure relates to a device comprising means for carrying out the steps of the method according to an embodiment of the first or second aspect.

[0071] In embodiments, the device may comprise an ultrasound detector (e.g. an ultrasound receiver or an ultrasound transceiver).

[0072] In embodiments, the device may comprise an ultrasound emitter (e.g. an ultrasound transmitter or an ultrasound transceiver).

[0073] In embodiments, the ultrasound detector and/or ultrasound emitter may be an ultrasonic transducer array.

[0074] In embodiments, the device may be a fingerprint scanner.

[0075] In embodiments, any feature of the third aspect or its embodiments may independently be as correspondingly described for embodiments of any other aspect.

[0076] In a fourth aspect, the present disclosure relates to a computer program product comprising instructions which, when the program is executed on a computer, cause the computer to carry out the steps of the method according to an embodiment of the first or second aspect.

[0077] In embodiments, any feature of the fourth aspect or its embodiments may independently be as correspondingly described for embodiments of any other aspect.

[0078] In a fifth aspect, the present disclosure relates to a computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the steps of the method according to an embodiment of the first or second aspect.

[0079] In embodiments, any feature of the fifth aspect or its embodiments may independently be as correspondingly described for embodiments of any other aspect.

[0080] In a sixth aspect, the present disclosure relates to a use of ultrasound imaging for visualizing an interface between an epidermis and an external environment, wherein the ultrasound imaging uses a null subtraction imaging technique.

[0081] In embodiments, the use may be for visualizing a fingerprint.

[0082] In embodiments, any feature of the sixth aspect or its embodiments may independently be as correspondingly described for embodiments of any other aspect.

[0083] In a seventh aspect, the disclosure relates to a device configured or adapted to carry out the steps of the method according to an embodiment of the sixth aspect.

[0084] The disclosure will now be described by a detailed description of several embodiments. It is clear that other embodiments of the disclosure can be configured according to the knowledge of the person skilled in the art without departing from the true technical teaching of the disclosure, the disclosure being limited only by the terms of the appended claims.

EXAMPLE

Visualizing a Wire Target in Water

[0085] A linear ultrasonic transducer array having a pitch equal to 100 microns was employed as a transceiver to image a wire target in water, using a 15 MHz ultrasonic imaging frequency. A plane wave emission was used, without focusing, neither in transmit nor in receive mode. Ultrasound images were then generated, each time by processing the ultrasound signal acquired from a single transmission event. FIG. **2** shows the achieved −6 dB acoustic lateral resolution for different processing techniques and processing parameters, in function of the number of elements used in the ultrasonic transducer array.

[0086] Curve **101** corresponds to the processing of the ultrasound signal by standard linear beamforming. As seen in FIG. **2**, a resolution of about 700 μm was achieved with standard beamforming using 10 or more elements. By comparison, a diffraction limited lower boundary of about 550 μm can be expected under these conditions.

[0087] Conversely, curves **102-105** correspond to the processing of the ultrasound signal by applying a 'bridging approach' null subtraction imaging, in accordance with embodiments of the present disclosure. The difference between curves **102-105** is in the value that was used for the DC bias in the generation of the apodized signals: 0.10 for curve **102**, 0.15 for curve **103**, and 0.20 for curve **104** and 0.25 for curve **105**. As seen in FIG. **2**, and regardless of the DC bias that was used, the achieved resolution is consistently better using null subtraction imaging than standard beamforming for a given number of elements. Furthermore, curves **102-105** converge for increasing elements, and the achieved resolution reaches a lower limit of about 100 μm for 8 elements and upwards; i.e. considerably below both the best practical optimum of 700 μm achieved with standard beamforming and the theoretical diffraction limited optimum of 550 μm. Super-resolution values are thus made accessible through null subtraction imaging. On top of that, the optimum was reached for 8 elements (compared to 10 for standard beamforming), indicating that furthermore fewer elements are needed when using null subtraction imaging.

[0088] The wire target in water in this example can be considered as a model case for the visualization of an interface between an epidermis and an external environment (e.g. for the visualization of a fingerprint). As such, similar results are expected for the visualization of such an interface.

[0089] It is to be understood that although example embodiments, specific constructions and configurations, as well as materials, have been discussed herein for devices according to the present disclosure, various changes or modifications in form and detail may be made without departing from the scope and technical teachings of this disclosure. For example, any formulas given above are merely representative of procedures that may be used. Functionality may be added or deleted from the block diagrams and operations may be interchanged among functional blocks. Steps may be added or deleted to methods described within the scope of the present disclosure.

[0090] While some embodiments have been illustrated and described in detail in the appended drawings and the foregoing description, such illustration and description are to be considered illustrative and not restrictive. Other variations to the disclosed embodiments can be understood and effected in practicing the claims, from a study of the drawings, the disclosure, and the appended claims. The mere fact that certain measures or features are recited in mutually different dependent claims does not indicate that a combination of these measures or features cannot be used. Any reference signs in the claims should not be construed as limiting the scope.

What is claimed is:

1. A method for visualizing an interface between an epidermis and an external environment, comprising:

a. acquiring an ultrasound signal of the interface using an ultrasonic transducer array, and

b. applying a null subtraction imaging technique to the acquired ultrasound signal, thereby forming an ultrasound image.

2. The method according to claim **1**, wherein acquiring an ultrasound signal of the interface comprises the substeps of:

a**1**. emitting an ultrasonic wave towards the interface, and

a**2**. receiving an ultrasound echo from the interface, thereby obtaining the ultrasound signal.

3. The method according to claim **1**, wherein applying the null subtraction imaging technique comprises the substeps of:

b**1**. applying a first apodization weight to the acquired ultrasound signal, thereby generating a first apodized signal,

b**2**. applying a second apodization weight to the acquired ultrasound signal, thereby generating a second apodized signal, b**3**. applying a third apodization weight to the acquired ultrasound signal, thereby generating a third apodized signal, and

b**4**. combining the first, second and third apodized signals to form the ultrasound image.

4. The method according to claim **3**, wherein the ultrasonic transducer array comprises a transducer array aperture and wherein the first apodization weight has a zero mean value across the transducer array aperture and wherein the second and third apodization weights have a non-zero mean value across the transducer array aperture.

5. The method according to claim **4**, wherein the second apodization weight is obtained by adding a DC bias to the first apodization weight and wherein the third apodization weight is a transpose of the second apodization weight.

6. The method according to claim **3**, wherein combining the first, second and third apodized signals comprises making a linear combination of the first, second and third apodized signals.

7. The method according to claim **1**, wherein acquiring an ultrasound signal of the interface comprises the substeps of:

a**1**. emitting an ultrasonic wave towards the interface, and

a**2**. receiving an ultrasound echo from the interface, thereby obtaining the ultrasound signal; and

wherein applying the null subtraction imaging technique comprises the substeps of:

b**1**. applying a first apodization weight to the acquired ultrasound signal, thereby generating a first apodized signal,

b**2**. applying a second apodization weight to the acquired ultrasound signal, thereby generating a second apodized signal,

b**3**. applying a third apodization weight to the acquired ultrasound signal, thereby generating a third apodized signal, and

b**4**. combining the first, second and third apodized signals to form the ultrasound image.

8. The method of claim **1**, wherein the ultrasonic transducer array comprises 2 or more ultrasonic transducer elements.

9. A method for scanning a fingerprint, comprising the method for visualizing an interface between an epidermis and an external environment of a finger according to claim **1** and further comprising a step c of:

c. processing the ultrasound image to obtain data indicative of the fingerprint.

10. A device configured or adapted to carry out the steps of the method according to claim **1**.

11. The device according to claim **10**, wherein the device comprises an ultrasound detector.

12. The device according to claim **10**, wherein the device comprises an ultrasound emitter.

13. The device according to claim **10**, wherein the device is a fingerprint scanner.

14. A computer program product comprising instructions which, when the program is executed on a computer, cause the computer to carry out the steps of the method according to claim **1**.

15. A computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the steps of the method according to claim **1**.

16. A method of using ultrasound imaging for visualizing an interface between an epidermis and an external environment, wherein the ultrasound imaging uses a null subtraction imaging technique.

17. A device configured or adapted to carry out the method according to claim **16**.

18. The device of claim **17**, wherein the device is a fingerprint scanner.

19. The method according to claim **16**, wherein the method visualizes a fingerprint.

20. The method of claim **16**, wherein the method further visualizes a layer beyond the interface.

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patsnap

专利名称(译)	Null减法成像技术的超声成像
公开(公告)号	US20200129157A1
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[标]申请(专利权)人(译)	校际微电子中心
申请(专利权)人(译)	IMEC VZW
当前申请(专利权)人(译)	IMEC VZW
[标]发明人	ROCHUS VERONIQUE
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摘要(译)

在第一方面，本公开涉及一种用于可视化表皮与外部环境之间的界面的方法。 该方法包括：（a）使用超声换能器阵列获取接口的超声信号；（b）对所获取的超声信号应用零差减法成像技术，从而形成超声图像。