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Research Article

Early Breast Lump Detection Using the Intelligent Bra "IN-bra"

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Abstract

This paper proposes a new smart Bra concept to detect any potential strange lumps in women's breasts by ultrasounds waves. These suspicious lumps can be a cyst, Abscess, Fibroadenoma, or Tumor. This system consists of 18 transducers positioned in a specific way, distributed on a ring, with a 5 MHz central frequency while respecting the anatomy of the breasts. We aim to minimize the main lobe's beamwidth (BW) and maximize the radiation field along the side lobes (SLL) of the transducer, with this wide lateral diffraction caused by the piezoelectric, we can detect any strange corps in the breast.

Our hypothesis was confirmed by the correlation coefficient formula, where two signals are compared according to their spatial resemblance potentially. According to our findings, there are no suspicious lumps in the breast, while the correlation coefficient is as high as 0.2.

Keywords: Breast Cancer; Smart Bra; Ultrasound; Tumor; Piezoelectric; Transducers

Introduction

With 1.7 million women diagnosed annually, breast cancer is the most common cancer in the world, ahead of colorectal cancer and lung cancer. Without any risk factors other than their age, women should be checked for breast cancer once a year after age 25, and once every two years between the ages of 50 and 74, in an organized breast cancer screening program. A mammogram is recommended as part of the screening process for women at risk of breast cancer, which is a painful procedure. More than 90% of cases of this pathology can be cured if they are detected at an early stage. Magnetic resonance imaging (MRI), x-ray mammography, and ultrasound are now among the most advanced methods for detecting and diagnosing breast cancer. Screening with mammography is the most effective and scientifically recognized method. Despite its effectiveness, this technique is hampered by several issues, including a lack of access to care, pain, and a delay in results. Because it is done by medical specialists, it is also considered too expensive for mass screening in several countries. Breast ultrasound imaging can help women under 45 years old achieve a more precise diagnosis. Mammography has improved in sensitivity for women over 60 years old, and it has become more accurate for women with larger and less dense breasts. To assess women with dense breasts who have no symptoms of breast cancer, (ABUS) Automated breast ultrasound can be used in combination with mammography. ABUS is a quick, safe, and non-invasive ultrasound exam [1] but we still need MRI to be more accurate. Recently, there have been different technologies developed in the form of bras to detect potential breast cancer, each of which works differently. In 2016, researchers at the National University of Columbia developed a prototype smart bra with integrated temperature sensors that could be useful for detecting breast cancer early by comparing the temperatures of the two breasts. When cancer cells are present in the breast, blood flow increases, causing tissue temperature to increase [2].

Moreover, Eva is a bio-sensing bra created in 2017 that uses thermal sensing and artificial intelligence to create a thermal map of a patient's breasts. Using Bluetooth, EVA will send the data to the app, which will analyze the results and provide an evaluation to the user, 87.9% of the devices' results showed a high level of sensitivity, while 81.7% showed a high level of specificity [3].

Furthermore, Project SBra (Smart Bra) created in 2019 an intelligent bra that integrates sensors that measure breast tissue impedance and skin temperature using electrical and thermal measurements of breast tissue [4]. Marie-Valerie Moreno and Edouard Herrera designed a bra in 2019 based on three sensors: temperature (breast thermography), photoplethysmography, and bioimpedance of the tissue [5]. Otherwise, EPFL students have developed a Smart Bra in 2019 that can be used to detect cancer with IcosaMed a start-up in Switzerland. This technology-based on frequent ultrasound monitoring is a non-invasive, painless procedure. The ultrasound waves are produced by piezoelectric sensors, which generate power when a piezoelectric material is excited [6].

Ultrasound waves are used by our team to diagnose potentially cancerous cells, instead of the existing invasive technology that relies on radiation or non-invasive that relies on temperature. IN-bra is a smart-clothing technology project to increase the clever bra sensitivity, which can effectively detect most cancers early, without difficulty, and danger to health. Women are considered to be in excessive danger and women who are not screened could benefit most from this gadget. Our ultimate goal is to develop an intelligent bra equipped with sensors that can diagnose a stranger corps (It might be malignant or benign) in the women's breast, comfortably, and without health risks. These suspicious lumps can be a cyst, Abscess, Fibroadenoma, or Tumor. The concept behind IN-Bra is to cover the hall of the breast with piezoelectric elements that are positioned specifically and to place the breast symmetrically with its middle axis as depicted in figure 1.

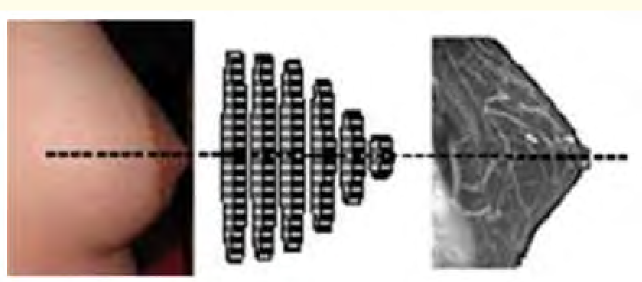

Figure 1: Our system covering the hall breast.

Women considered to be at high risk would be the primary target of the device, not women scheduled for routine screenings or checkups. By using this technology, we avoid exposure to radiation every six months at least. The wearer will receive an alert if the system detects a suspicious mass of cells so she can schedule a specialist appointment.

Materials and Methods

Physical approach

Anatomically, the breast is composed of glandular, fibrous connective, and fatty tissue. Physiologically, the breast is a relatively uniform organ with around twenty identical lobes situated symmetrically around the nipple. The abnormal growth of cells within the breast (especially those lining the ducts and lobules) causes breast cancer. Breast cancer tumors are incredibly stiff compared to normal tissue. To describe the size and stage of a tumor, actually, the TNM system uses the letter "T" plus a number (0 to 4). Below are the details of each stage.

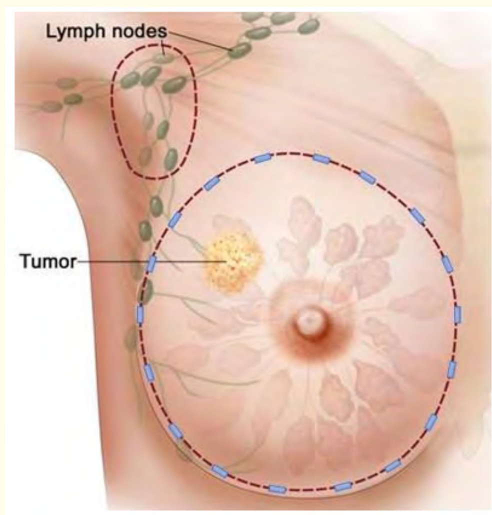

Figure 2: An image of the breast morphology, showing the tumor and 18 transducers scattered around (in blue) (https://visualsonline.cancer.gov/details.cfm?imageid=7129).

T1: The tumor in the breast is smaller than 20 mm.

T2: The tumor is between 20 mm and 50 mm.

T3: The tumor is larger than 50 mm.

T4: Means the tumor has grown into the chest wall or the skin the chest wall and the skin or inflammatory breast cancer [7].

A total of 25% of all imaging examinations performed in the world today utilize ultrasonic imaging as the primary diagnostic imaging modality. Ultrasound is generally used for diagnostic imaging in the frequency range of 2 to 15 MHz. Generally, the mean absolute sound speed in the fatty tissue segment was 1457 m/s, in the glandular and fatty tissue segments, 1470 m/s, and in tumorous tissue, 1509 m/s.

We have developed an ultrasound approach based on this observation that favors the phenomenon of diffraction of secondary lobes of the emitted field in a lateral section of the breast. Lockwood and Willette [9] developed a formula that characterizes ultrasonic impulse responses through multiple backscattering. Thus, suspect cell biomasses can be considered secondary sources, delimiting the Regions Of Interest (ROI). A threshold of critical correlations between ultrasonic signals reduces the effects of phase fluctuation while allowing an inspection of suspected zones.

In fact, the sound speed in tumorous tissue was significantly higher than in glandular and fatty tissues [8]. When the wave passes through the tumor, its characteristics are modified (velocity, amplitude, diffraction, ...). Part of this wave is reflected as depicted in figure 3. Our device relies on the reflection of waves from the strange body in an environment that has its characteristics. This Scattering/reflection caused additional acoustic pressure on the sides where are located this body.

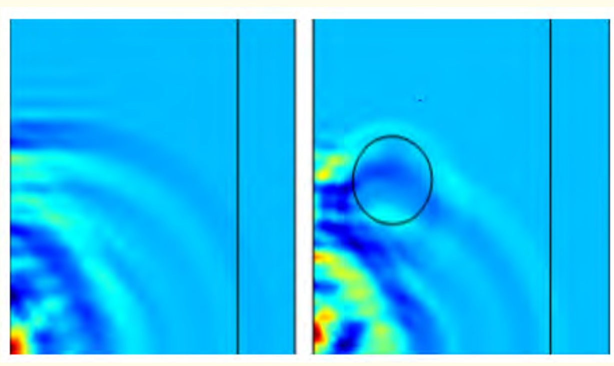

Figure 3: Comparison of two waves produced by two transducers that have the same features in Fat medium, the left one without a strange body and the right one with a strange body has a skin property.

Ultrasonic field radiation

As mentioned below, regarding the field radiation of transducers, we focus on the choice of the physical characteristics of the vibrating element to minimizing the main lobe's beam width (BW) and maximizing the side lobes level (SLL) as shown in figure 4.

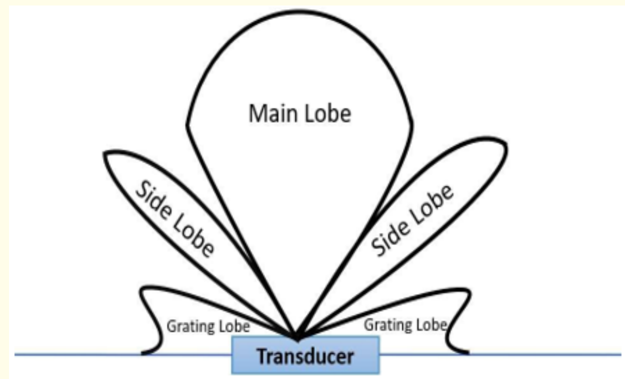

Figure 4: Image of an ultrasonic signal's main lobe, side lobes, and grating lobes in two dimensions.

According to the pattern multiplication theorem, there are no other grating lobes in the visible space when the array spacing is less than or equal to λ/2. A grating lobe appears when the spacing between arrays is greater than λ/2. Even at a zero-scan angle, grating lobes may appear in the visible space when the spacing is large. An increase inside lobes can be observed when the element spacing is increased by one wavelength. The grating lobes appear in the visible region when the element spacing is increased to 1.5 wavelengths apart. Or, in our device, each transducer is separated by a distance of more than λ to avoid the pattern multiplication theorem. The is characterized by this equation:

Where intensity of the beam in a specific angle.

Hence, we reduce the width a to be << to the length b, to produce the maximum diffraction possible

Where a is the width and b is the length of the transducer, is the beam angle in the XOZ plane and is the beam angle in the YOZ plane. We find that when we reduce the width a to be << to the length b, to produce the maximum diffraction possible θ.

We create a FEM model of the women's breast in 3D using COMSOL Multiphysics to arrive at a solution, as shown in figure 5. A circular array of rectangular piezoelectric was placed around the breast, a cyclic protocol was used to transmit and receive an electric pulse. The transducer plays the role of a transmitter and the one before and the one after plays the role of a receiver. A skin breast fat tumor and breast gland are implemented with their electric and mechanical features. Taking a breast with a radius of 14 cm.

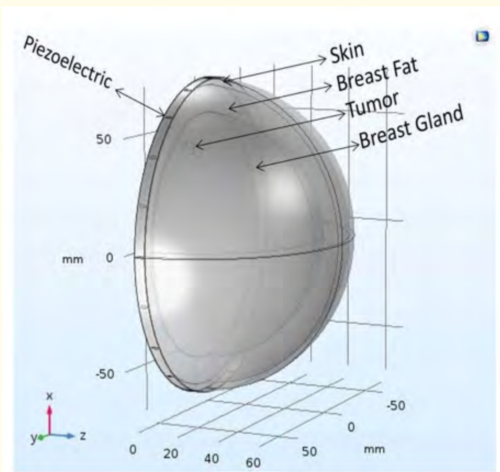

Figure 5: FEM 3D model of the female breast with tumor.

The piezoelectric should be oriented in a tangential and parallel configuration to the axis of symmetry of a breast, as depicted in figure 6, so that the piezo diffraction propagates laterally through the medium. In this finite element method, we used extremely fine meshing size with a perfect distribution on the piezoelectric to identify the acoustic pressure on his surface.

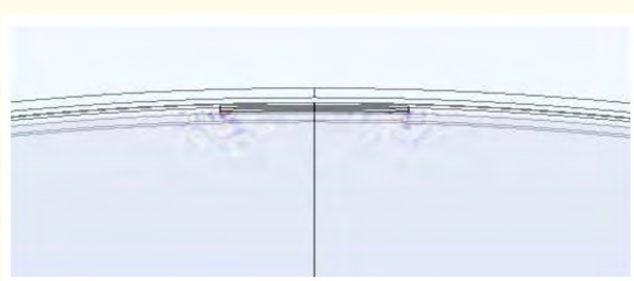

Figure 6: 3D plot for a Piezoelectric that shows the side lobes working intensely.

Hence, the skin part was selected as a PML (perfectly matched layers) to simulate electromagnetic waves that propagate into an unbounded domain, that action due to absorbing all radiated waves with small reflections.

An electric pulse generated by an external source excites the transducer to activate our mechatronics system. The voltage source type is a modulated Gaussian pulse, defined as:

In this case, the location is defined as 0,97*2/f0, and the standard deviation as 1/(2f0). To improve frequency response, the location of the Gaussian pulse is slightly shifted from twice the period time by a factor of 0,97.

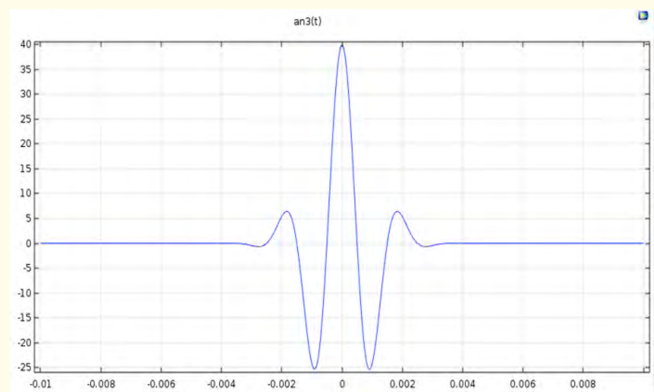

Figure 7: Modulated Gaussian Pulse.

The Measurement of the relationship between two signals received by R(k+1) and R(K-1) is done by using correlation coefficients following this equation below:

In the case of a correlation approaching 0.0, there is no linear relationship between the two signals. There are 18 transducers, each one with a different label and its changes based on the work he has done: RK: is the transducer while he received signals, EK: is the transducer while he emitted source, CK: Is the correlation between R(K+1) and R(K-1), While K is between 0 and 18.

Results and Discussions

Conventional bidirectional wide-field ultrasound does not take into account an element which is the symmetry in the distribution of the mammary glands in the anatomy of the breast. However, since these two factors vary more or less from person to person, our approach not only provides a positional reference, but also a binary inspection strategy for identifying suspicious zones. Therefore, our physical model (in the design of a global system) is based on the equidistant distribution of ultrasonic sensors with circumferences of different diameters centered on the horizontal axis passing through the nipple.

With the proposed approach, the acoustic pressure data are calculated over the skin within a frequency range of 5 MHz concerning the variation of the tumor size of 10 mm radius and 25 mm radius. It is found that the slope of acoustic pressure vs. time is increasing with the increasing tumor size. Figure 8 shows the difference between the presence of a tumor and her absence while exciting E01 and E10. As shown in the picture below, the acoustic wave avoids the tumor's path and a part of the wave is reflected on the transducer R02. Acoustic pressure in specific locations is affected by the presence of tumors, most notably on R02, and R18, and less on R09 and R11.

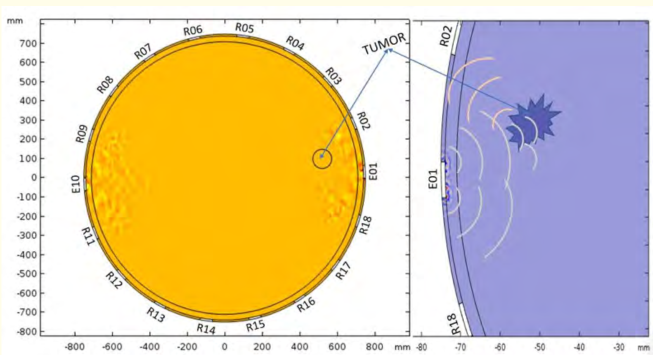

Figure 8: The left image depicts a 2D plot of a lateral section of the breast, as for the right one it is the way the acoustic wave is diffracted from the emitter to the receiver.

In this study we aimed to improve the detection threshold of the ROIs which was the subject of the work of Godih., *et al*. [10] and this by optimizing both the spatio-temporal characteristics of the acoustic field and the algorithm associated with the detection. The purpose is to bring an improvement on the sequential triggering in emission/reception with an ultrasonic radiation field covering a plane (Figure 8 and 9) of a transverse section of the breast. Our main objective is to realize a concept of binary detection as criteria (Yes or Not) of a risk on the existence of a tumor while alerting the health specialist for the care of the patient.

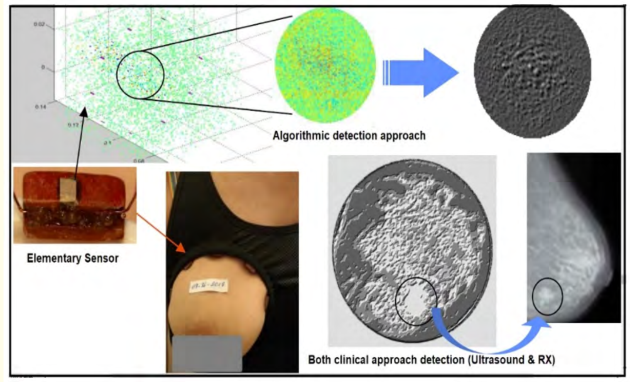

Figure 9: Clinical application showing the concordance between Ultrasound and RX speckle detection [10].

It should be noted that in previous works, and for an ethical question, a population of 5 subjects was examined. The results of figure 9 shows a practical example on the detection of suspicious areas by the ultrasonic way confirmed by the radio technique (RX).

By using the symmetric distribution in the morphology of the breast and with respect to a central as shown figure 1, our concept focuses on the way that when the E(K) is the ultrasonic source, a series of tests must be performed to compare each of the two signals received by the receptors R(K-1) and R(k+1).

We applied a modulated Gaussian pulse to the transducer E10, and then another pulse is applied to the transducer E09, and so forth. This is to close the loop on the last transducer, E11. When a transducer acts as an emitter (EK), the transducers on the left R(K-1) and the right R(K+1) act as receivers, and the coefficient of correlation algorithm is used to compare the two signals received by the receivers R(K-1) and R(k+1) on either side of the emitter (EK).

The location of the tumor and the voltage on the sources were fixed throughout the process and data acquisition so that we could compare the acoustic wave on all the sensors and find variations, and see if we could figure out where the tumor was. We obtain 9 graphs in all, each with two signals from the two receivers around the emitter. Only two graphs were shown in this work to demonstrate the difference between the wing where the lump is placed (Figure 11) and the other side where there is no 'strange body' in the medium (Figure 10). This procedure can be done several times to obtain an average reading on each sensor and ensure the accuracy of the data.

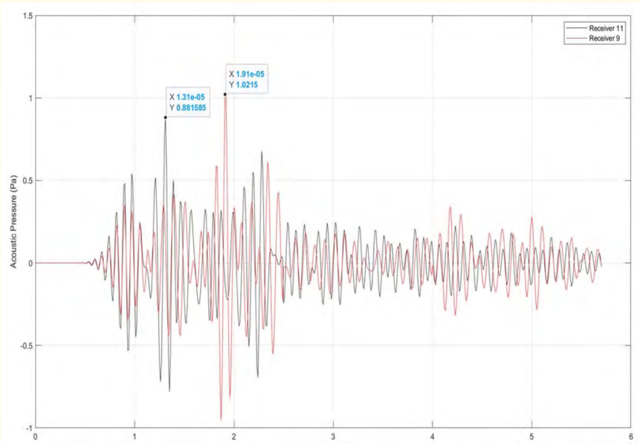

Figure 10: When the tumor size is 20 mm and E10 is activated by an electric pulse, the black signal is on R11, and the red signal is on R09.

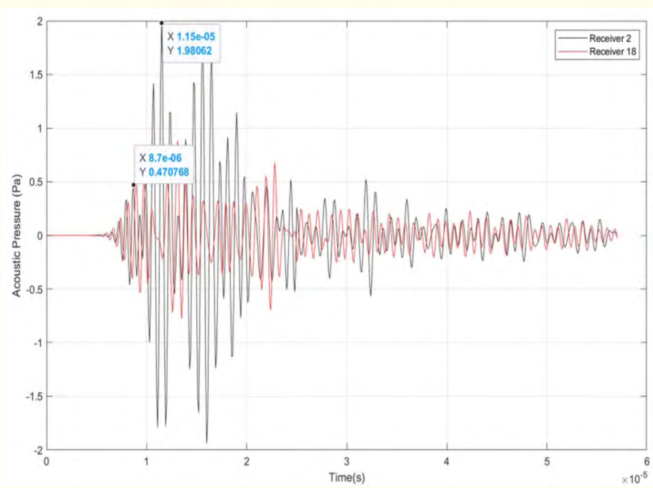

Figure 11: When the tumor size is 20 mm and E01 is activated by an electric pulse, the black signal is on R02, and the red signal is on R18.

The graph in figure 10 shows that there are two signals with a 58.6 percent similarity. We can observe that for these two signals, the maximum acoustic pressure is around 1 Pa. The measurement is required near the R11 and R09 piezo, which function as receivers.

Two signals are received by R02 and R18 in Figure 11. There is a 12.3% similarity between the two signals. The acoustic pressure amplitude of the R02 is around 2 Pa, whereas that of the R1 is approximately 1 Pa.

We took all the values under 2E-4 seconds to identify just the waves reflected by the foreign body in this heterogenic medium. As our findings show, there is an increase in sound pressure on the side where the tumor is located, resulting in a decrease in the correlation between the two signals. We can conclude that a suspicious lump is found when the coefficient correlation is less than 0.2. Figure 12 shows the decrease of the curve between C03 and C18, which is where the strange body is located, as seen in figure 8.

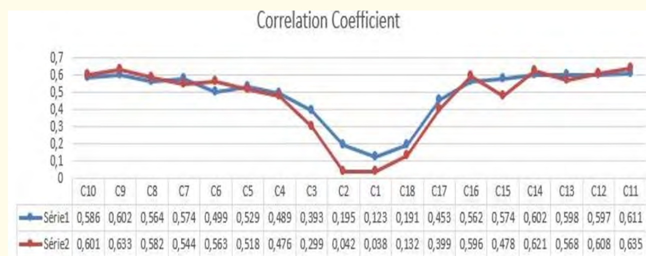

Figure 12: Correlation coefficient variation while the periodic pulse moves from E1 to E18 and comparing the R(K+1) to R(K-1).

An AI system will be installed in the bra covering the entire breast to ensure the consistency of the measuring parameters, making this concept valuable, reliable, and safe. If required, microinjections of medical gel between the sensor and the breast can be used to enhance the transition and the reliability of the information delivered by the ultrasonic signal. The IN-bra will also have a communication module and a smartphone interface, allowing the overall concept to be autonomous and connected to the client.

Conclusion

We have discussed an ultrasound approach to early detection of breast diseases with a promising application giving health professionals easy access to simple diagnoses to improve clinical management and therapeutic outcomes. Using IN-bra of a smart bra will eventually be able to identify risk areas of the breast as a whole thereby avoiding, as far as possible, the need to expose people at risk to X-rays (in mammography). The long-term objective is to integrate this device with communication systems (smart phones) through a prevention application connected to a specialized center.

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