Identifying Benign and Malignant Breast Tumor Using Vibro-acoustic Tactile Imaging Sensor

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Abstract— **Tactile imaging sensor determines the tumor's mechanical properties such as size, depth, and Young's modulus based on the principle of total internal reflection of light. To improve the classifying accuracy of the Tactile imaging sensor, we introduce ultrasound signals and estimate the difference in the tumor tactile images. A developed vibro-acoustic tactile imaging sensor was used to classify benign and malignant tumors. We test the developed system on breast tumor phantoms. These vibrated tactile images are analyzed to improve the overall performance of tumor detection.**

Keywords— tactile sensing, vibro-acoustic, ultrasound, image diameter, risk score, elasticity

I. INTRODUCTION

More than 1.3 million women worldwide are diagnosed with breast cancer each year [1, 2]. While many women have access to health care and cancer screening, those living in rural or underdeveloped areas frequently do not. As a result, there is a need for an inexpensive and easy-to-use breast cancer detection device that can be used in small clinics to assist primary care physicians. Breast cancer occurs when breast cells begin to multiply uncontrolled. These cells usually form a lump called a tumor which can be categorized into two classes namely benign and malignant. Although a benign tumor is harmless, a malignant tumor attacks other normal organs by infiltrating them. Therefore, early detection of breast cancer is critical for a good prognosis and positive treatment outcomes. Several imaging modalities have been developed to detect initial symptoms of breast cancer.

A frequently recommended clinical imaging technique is mammography. Mammography is a visualization of breast tissue by using low-dose X-rays either as screening mammography or as diagnostic mammography. However, it is not a routine screening modality in females younger than 40 years of age, in part due to the dense glandular tissue as well as the hazard of ionizing radiation [3]. Ultrasound screening is another method of detecting breast cancer. It involves transmitting sound waves through a transducer that sends pulses into the breast and detects echoes from within; these echoes are used to create ultrasound images. This method has higher sensitivity and lower specificity than mammography [4]. Compared to mammography and ultrasound techniques, MRI is highly sensitive in detecting invasive and small abnormalities and can be used effectively for patients with dense breasts. Testing using MRI, however, is relatively expensive. [5].

To overcome the limitations of conventional clinical imaging techniques, many researchers are working on developing different non-invasive modalities for breast tumor characterization. A research group [7] at the University of British Columbia developed a system using vibroelastography to compute the mechanical properties of breast tumors. This system used ultrasound to image the dynamic deformation of tissue while an actuator created multiple frequencies of surface vibration. They found that multiple frequencies enhanced the process of tissue characterization. Another group [1] employed vibration analysis with a pushing cylinder method to distinguish the normal tissue and tumors. They used air injection to vibrate the phantom. After that they calculated the displacement difference rate by comparing the displacement of the phantom with and without tumor for two distinct experiments. They found that by pushing cylinder, the displacement rate increased, allowing for a more accurate distinction between normal tissue and tumors. The authors in [13] utilized vibro-acoustography as a breast imaging method to detect benign and malignant inclusions in the breast. Their system used the radiation force of ultrasound waves to cause breast tissue to vibrate. Additionally, a hydrophone was utilized to detect the sound created by breast motions and create an acoustic image of the breast. This vibro-acoustic imaging system's specificity was 94% and its sensitivity ranged from 69% to 100%. Building on these results, we utilize ultrasound to generate vibroacoustic signal and create vibration in tumor while taking tactile images. Over the last two decades, considerable efforts have been devoted to developing a tactile sensing-based system to estimate tissue stiffness on a variety of transducing mechanisms [8]. Our research group developed a Tactile Imaging System (TIS) [6, 9] to measure the mechanical properties of tissue inclusions. TIS showed an accuracy of 90% in identifying malignant tumors [10]. The same group also developed a smartphone based TIS called, compression-induced sensing system [10] in 2018. Based on the estimated mechanical properties, they developed a risk score to classify the tumor as benign or malignant. In this paper, we incorporate vibro-acoustic signals with tactile images to improve tumor characterization accuracy.

Previously, different groups worked on tactile and vibro-acoustic imaging systems separately. However, in this paper, ultrasound is used with a previously developed [9] tactile imaging system to improve the overall sensitivity and specificity of the tumor detection. The ultrasound caused vibration in tumor embedded phantom and TIS captured the images based on the total internal reflection principle. After processing the recorded information, mechanical properties such as size, difference in the image diameter (Δ_{dia}) and risk

score are calculated to differentiate the benign and malignant tumor.

The remainder of the paper is structured as follows: Section II presents the experimental setup and sensing principle of the system. It also discusses the algorithms to estimate the size, Δ_{dia} and risk score of the tumor. The result of the experiment is summarized in Section III. Section IV presents a discussion and conclusion along with future aspects of research.

II. METHOD

A. Tactile Imaging Sensor and Sensing Principle

A tactile imaging sensor (TIS) contains a soft and transparent sensing probe (20 mm × 23 mm × 14 mm) with the elastic modulus of 27.16 ± 0.57 kPa, four white LEDs (each 1500 mcd) as a light source, a CCD camera unit with an image resolution of 752 pixels × 480 pixels and an external force gauge (Mark-10 Series 3, Mark-10, Long Island, NY) on the top of the camera to measure the applied force. It can measure force from 0 to 50 N with a resolution of 10 mN. To capture the image total internal reflection of light is used in TIS. Without any pressure being sensed on the sensing tip, the camera does not record any light information. The camera records light information only when there is pressure on the tip to scatter the incident light. Furthermore, a computer is used to convert the light information to pixel data.
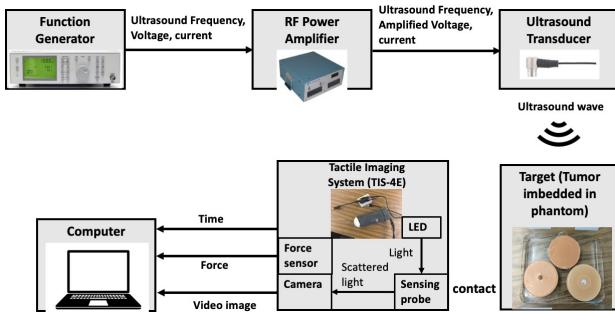

Fig. 1 : Experimental Setup of vibro-acoustic tactile imaging sensor.

Figure 1 shows the experimental setup of an vibro-acoustic tactile imaging system. In the experiment, an ultrasound wave of varying frequency (0.4-0.6 MHz) is used to vibrate the soft and hard tumor embedded in the phantom. PM 5136 function generator is used to generate the ultrasonic signal. Normally the reflected ultrasonic signal of such an ultrasound device is so small that a signal with an appropriate power amplifier output is required for accurate detection [12]. So, to boost the excitation signal to the ultrasonic transducer, a class AB RF power amplifier is inserted between the function generator and the ultrasonic transducer. TIS is used to capture information about the experiment such as image, applied force, and time. Further, this information is sent to the processing unit to compute the size, Δ_{dia} and risk score value of the tumor.

Here, the experiment is performed under the following two conditions: (1) With TIS only, and (2) Including varying ultrasound (0.4-0.6 MHz) wave with TIS.

B. Tumor Size Estimation

Images captured by the camera are further processed to estimate the size of the tumor using a 3D interpolation model [10]. This model finds the relation among applied force, F, the sum of pixel intensities for the corresponding images, N_p and diameter of the tumor, D. For different depth layers and size inclusions, multiple surfaces ($p_{i,j}$) are modeled to estimate the size of the tumor using Eq. 1.

$$D(F, N_p) = \sum_{i=0}^{i=n} \sum_{j=0}^{j=m} p_{i,j} F^i N_p^j \quad (1)$$

Here, we developed a third-order polynomial surface for our model with indices, $n = 2$, $m = 1$.

C. Delta (Δ_dia) Estimation

The amount at which the diameter of the tumor changed due to the applied vibration is called Δ_{dia}, which is calculated using Eq. 2,

$$\Delta_{dia} = d_u - d_{wu} \quad (2)$$

Here, d_u and d_{wu} are the diameter of the tumor after and before applying the ultrasound wave respectively. Under the condition that the applied force, ultrasound frequency, and depth of the tumor phantom are kept constant, the softer inclusion had a smaller change than the stiffer inclusion. Hence the Δ_{dia} for stiffer inclusion will be higher than the softer inclusions.

D. Risk Score Estimation

To detect the tumor as benign or malignant, a unitless numerical value named risk score is developed. This scoring value can be calculated by using the value of estimated size and change in diameter (Δ_{dia}) of the tumor. It ranges from 0 to 5, where 0 defines benign and 5 malignant. This score can be found using the following Eq. 3.

$$\text{Risk Score} = \left[\frac{W_1 \times S}{S_{max}} + \frac{W_2 \times \Delta_{dia}}{\Delta_{dia(max)}}\right] R \quad (3)$$

where W_1 and W_2 are the two weights used for size and delta, respectively, S represents the estimated size value, S_{max} is the maximum estimated size value, Δ_{dia} is the change in area due to ultrasound wave, $\Delta_{dia(max)}$ is the maximum delta value. R = 5 is the highest value of the Risk Score used. To classify tumors, we choose the pair of weights W_1 = 0.3 and W_2 = 0.7). As we have limited data set, we used the value of weights from [10]. To differentiate the tumor type, a marginal threshold value is set, where any risk score below the threshold is considered benign. Here the threshold value is set arbitrarily as 3 based on the experimental result of data sets.

III. RESULT

For this experiment, the same depth phantom (10 mm) was used for both experiment 1 (benign 11.52 mm, malignant 13.75 mm) and experiment 2 (benign 12.20 mm, malignant 12.04 mm). We applied ultrasound frequency on the phantom in the range of 0.4-0.6 MHz and captured the images with TIS. To compare the effect of ultrasound,
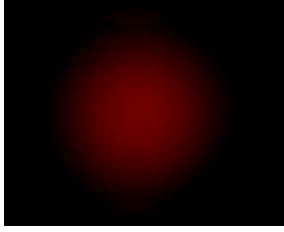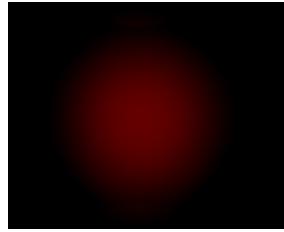
(a) Vibro-acoustic signal off   (b) Vibro-acoustic signal on

Fig. 2: Benign tumor (Inclusion size = 11.52 mm, 0.60 MHz, 32 N

images were captured both with and without ultrasound cases.

From the resulted images given in Figure 2, it could be observed that no significant change is noticed in the benign tumor after applying ultrasound.
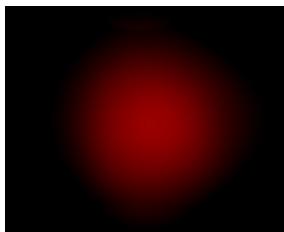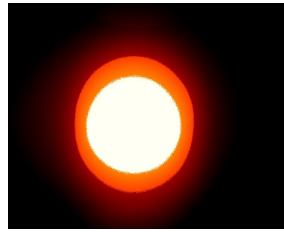
(a) Vibro-acoustic signal off   (b) Vibro-acoustic signal on

Fig. 3: Malignant tumor (Inclusion size = 13.75 mm, 0.60 MHz, 32 N

In the case of a malignant tumor, it could be observed from Figure 3 that vibration resulting from the ultrasound wave created a more vivid and enlarged size image of a malignant tumor. In the case of benign tumors, this change is very small. To measure the change, the difference in diameter of the tumors before and after applying ultrasound wave is considered. To calculate the diameter, we experimentally set a threshold value of 10 for each pixel of the images. The pixels larger than the threshold are then set to 1 and the others are set to 0, which results in a binary image. The diameter in the pixel is calculated by averaging the major and minor dimensions of the image.

Here, the circle is drawn for the estimated diameter. Similarly, binary images for all other samples are formed and diameter is calculated using Eq. 2. We varied the frequency from 0.4-0.6 MHz. To find the optimized frequency, the Δ_{dia} value for both benign and malignant tumors is plotted with the varying frequency in Fig. 4.

From Fig. 4 it can be observed that maximum separation between benign and malignant tumors is observed at 0.6 MHz. Because maximum separation ensures better classification, based on limited data sets and frequency range, the optimized frequency is determined as as 0.6 MHz.

Now, based on the estimated size and Δ_{dia}, the risk score is calculated. To classify tumors, the threshold value for risk score is selected arbitrarily as 3. Below this threshold value, the tumor is considered benign. The experimental result is summarized in Table 1.
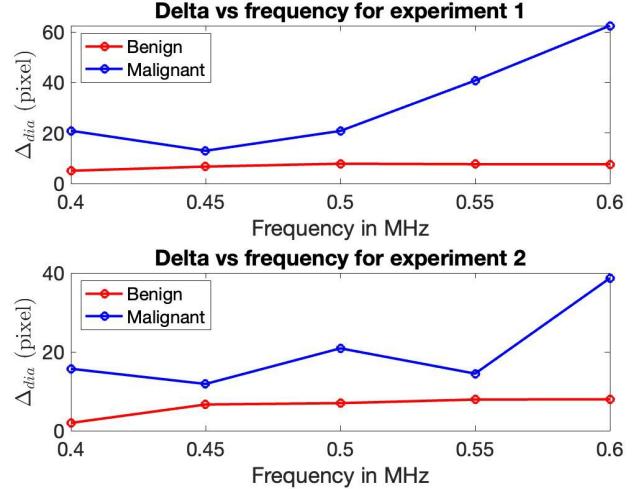

Fig. 4: Change in tumor diameter with varying frequency

This small set (four) of tumor samples is classified correctly (100% accuracy) based on the risk score values.

TABLE I: Risk Score based classification of tumor

Tumor Info.	True size (mm)	Est. size, S (mm)	Δ_{dia} (pixel)	Risk score	Classified tumor
Benign	11.52	13.06	7.62	1.83	Benign
	12.20	14.65	7.97	2.01	Benign
Malignant	13.75	12.34	54.09	4.76	Malignant
	12.04	13.54	38.68	3.89	Malignant

IV. DISCUSSION AND CONCLUSION

The developed ultrasonic tactile imaging system is used to classify the tumor as benign or malignant based on the proposed Risk Score. For our limited data sets, all the tumors are correctly classified as benign or malignant based on the estimated risk score; 100% accuracy for four phantoms. The vibration introduced by the ultrasound wave enhances the separation between benign and malignant tumors. Overall, we conclude that combining the features of vibro-acoustic with TIS improves the accuracy of tumor characterization.

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