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Tactile Sensation Imaging Technique for Embedded Lesion Detection

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Abstract*-- *In this paper we proposed tactile sensation imaging technique with supple waveguide and total internal reflection principle. The technique can also be used to detect and identify enclosures within tissues. In order to examine the performance of the proposed sensor, a realistic tissue vision with inclusions are integrated to emulate the tumors models. The proposed tactile imaging sensor can be implemented within inclusion diameter of 4.09% and the inclusion depth within 7.55%. From the planned characterization method the size, depth, and Young's modulus values are calculated using FEM and LMA algorithm.

Index Terms*— *Tactile sensation imaging, Inclusion, FEM, LMA, Total internal Reflection.

I. INTRODUCTION

Identifying early formation of tumors particularly those caused by cancer, has been a challenging problem. In order to help t h e physicians to detect tumor m or e efficiently, various imaging techniques like, computer tomography (CT), ultrasonic imaging (US), magnetic resonance imaging (MRI), and mammography (MG) are used. However, each of these techniques has disadvantages: harmful radiation to the body (CT, MG), low specificity (MRI), complicated system (MRI), low image resolution (US), etc. Artificial tactile sensors are a valuable non-invasive tool for the medical society, where physicians use tactile sensation to identify malignant tissue [4], [5]. Traditionally physicians have used palpation to detect breast or prostate tumors, which is based on the observation that the tissue abnormalities are usually associated with localized changes in mechanical properties such as stiffness [6].An artificial tactile sensor can accurately quantify and record thetactile sensation of benign and malignant regions. In this paper, we present a newly proposed tactile sensation imaging sensor to detect or locate sub-surface inclusions such as tumors or lumps. Polydimethylsiloxane (PDMS) is used to make a multi-layer optical waveguide as a sensing probe.

The mechanical properties of each layer have emulated the human finger layers to maximize the touch sensitivity. In this sensor, total internalreflection principleis utilized to obtain the high resolution of the tactile image. A force applied to an elastic waveguide, while light passes through it, causes change in the critical angle of internally reflected light.

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This results in diffused light outside the waveguide that is captured by a camera. The sensitivity and the resolution of the proposed sensor are controlled by the size of the waveguide and the light source intensity. This paper is organized as follows: Section 2 discusses the proposed sensor design and sensing principle. Section 3 presents the experimental arrangement for inclusion detection in a phantom. Finally, Section 4 presents t h e conclusions and discusses the future wor k.

II. TACTILE IMAGING SENSOR DESIGN AND SENSING PRINCIPLE

In this section, we present the design concept and sensing principle of the proposed sensor in detail.

2.1. Tactile Image sensor design

Fig. 1(a) shows the schematic of the tactile imaging sensor. The sensor comprises of an optical waveguide unit, a light source unit, a light coupling unit, a camera unit, and a computer unit.

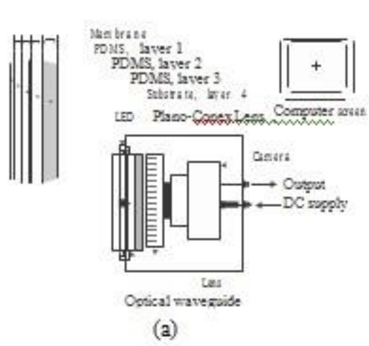

Fig. 1. (a) The schematic of the tactile imaging sensor.

The optical waveguide is the main sensing probe. It is composed of three polydimethylsiloxane (PDMS, Si (CH3)2) layers, which is a high performance silicone elastomeric [6]. The elastic modulus of each PDMS layer is matched as the

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modulus values of epidermis (1.4×105 Pa), dermis (8.0 ×104 Pa) and subcutaneous (3.4×104 Pa) of a human fingertip to realize the sensitivity to the level of the human touch sensation [7]. The digital imagery is a mono-cooled complementary camera with 4.65 μm × 4.65 μm individual p i x e l size. The maximum l en s resolution is 1392 μm (H) ×1042 μm (V) with 60o view angle. The camera is placed below an optical waveguide. A borosilicate g l a ss plate is placed as a substrate between camera and optical waveguide to sustain t h e waveguide without losing camera resolution. The glass plate emulates th e bone in the human fi n ger t i p . The internal light source is a micro-LED with a diameter of 1.8 mm. There are four LEDs used on four sides of the waveguide to provide enough illumination. The direction and incident angle of the LED light have been calibrated with the acceptance angle and it is discussed in the next section.

2.2 LMA and FEM

The forward algorithm is designed to predict the tactile parameters (maximum deformation, total deformation, and de- formation area) based on the parameters of the tissue inclusion (size, depth, and modulus). Then these results are used in the inversion algorithm. In the inversion algorithm, we use tactile parameters obtained from the TSIS and simulated values from the forward algorithm to estimate the size, depth, and modulus of the embedded lesion. The proposed method is then validated by the realistic tissue phantoms.The LMA interpolates between the Gauss-Newton algorithm (GNA) and the gradient descent method. The LMA is more robust than the GNA, which means that in many cases it finds an optimal solution even if it starts very far off the final minimum.

III. INCLUSION DETECTION

In this section, we performed the inclusion detection experimentsusing the tactile imaging sensor.

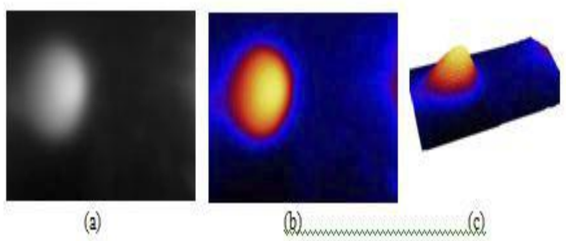


Fig. 2. The tactileimage of inclusion with 3.29 diameters placed atthe 4.2 mm depth. (a) Grey scale tactile image, (b) Color visualization, (c) 3-D reconstruction.

3.1 SYSTEM DESIGN CONCEPTS

In this section, the design concept of TSIS. Then the tactile sensation imaging principle based on the TIR phenomenon is discussed. The numerical simulations are verified by the principle behind TSIS. Finally, shall obtain tactile images of Phantom tissue inclusions.

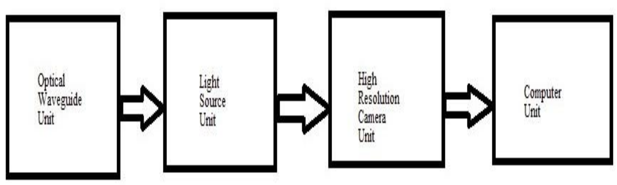
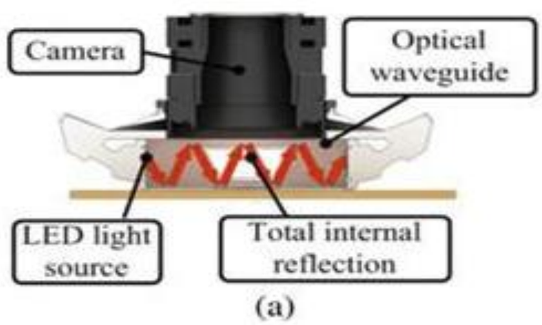


Fig 3. Block diagram of TSIS system



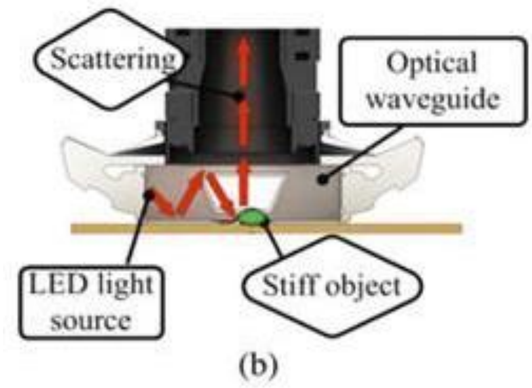


Fig.3.1. Concept of the tactile sensation imaging principle. (a) Light is injected into the waveguide to totally reflect.(b) Light scatters as the waveguide deforms due to the stiff tissue inclusion.

3.2 Inclusion diameter and depth estimation

The inclusion parameter estimations (i.e. Diameter and depth) based on the obtained tactile image can be formulated as an inversion problem. The integrated pixel value of tactile image is taken as input for the problem. For the inclusion diameter estimation experiments, twelvenew inclusions were embedded into the tissue with the same depths of 4.2 mm the inclusion diameter within 4.09% and the inclusion depth within 7.55%. So far we have determined either the diameteror the depth of the inclusions. The next step is to determine both diameterand depth ba sed on one tactile image.

3.3 Empirical Equation of Inclusion Characterization

For the experiments, a tissue phantom with embedded hard inclusions (simulated tumor) has been developed. The phantom was made of a silicone composite having Young's modulus of approximately 5 ∼10kPa. To find the relation between tactile image and inclusion size, total of nine inclusions with different diameters were placed below the surface of the phantom. The inclusion was made using another silicone composite, the stiffness of which was much higher (300 ∼500kPa) than th e surrounding tissue phantom. The depth of each inclusion was 4.2 mm. To find the relation between tactile image and inclusion depth, eight inclusions were placed in the tissue phantom with varying depth. The diameterof each inclusion was 5.15 mm. The tactile images of each inclusion were obtained under the normal force of between 10 mN and 20 mN.

The curve fitting method was used with these empirical measurements.

$$P1 = (1.0 \times 107)[1.0 \times 10-3D + 1.21], \quad (1)$$

$$P2 = (-1.0 \times 107)[4.1 \times 10-2H - 2.06]. \quad (2)$$

Where D is the inclusion diameter and H is the inclusion depth. P1 and P2 arethe integrated pixel value for different inclusion diameter D and depth H. Eq. (1) and (2) will vary with the thickness and the modulus of the surrounding tissue sample.

IV. CONCLUSION

In this paper, a new tactile sen sation imagin g method for Tumor identificationis proposed.To increase the sensitivity of touch, an optical waveguide consisting of three different elastic module of PDMS is fabricated as the sensing probe. This study is the initial step toward achieving a TSIS and associated parameter estimation method for early breast tumor detection and characterization.

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