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Prediction of Tumor Existence in the Virtual Soft Tissue by Using Tactile Tumor Detector

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Abstract: We proposed a method to investigate the effects of the tumor existence that appear on the surface of the tissue. Finite element analysis provided properties such as the shape, depth, and location of the tumor which are important parameters for physicians to distinguish the correct condition of the patients. Several different cases were created and solved by the ANSYS software and Tactile Images and Stress Graphs were extracted. These results clearly showed the existence of the tumor in the tissue. Having made an artificial tactile sensing system, called "*Tactile Tumor Detector*", which consists of three main components namely: tactile probe, tactile data processor and tactile display and having performed a number of experiments, we obtained good agreements between the numerical and experimental results. In addition to anticipating the presence of a tumor in the tissue and locating the exact place of the tumor, the experimental results help the user to predict the depth of the tumor inside the tissue.

Keywords: artificial tactile sensing, finite element analysis, biological tissue, tumor

INTRODUCTION

In clinical practice, the doctors routinely palpate the patients' body, especially for those diseases where a palpable nodule is the most common symptom such as the breast tumors. Even if the nodule is detected via palpation, due to the lack of any precise measuring devices, all that can be documented is the general location of the tumor[1]. The artificial tactile sensing is a new method for obtaining the characteristics of a tumor in the soft tissue[2-4]. This includes detecting the presence or absence of a tumor or even mapping a complete tactile image[5-7]. In some patients, this technique has preference over some imaging techniques. For example, 12% to 15% of cancers that are detected by palpation cannot be diagnosed through mammography. The reason is that this method is not applicable in some parts of the body such as the chest wall or the axillia [8]. Artificial palpation is another important application of tactile sensing which uses force and position signature factors [9]. Tactile and visual sensing are of great importance in different types of surgeries, and the reliability and accuracy of the artificial tactile sensing approach for the detection of tumors in simulated biological tissues using finite element method are proved[10-12]. In this regard, Minimally Invasive Surgery (MIS) is now being widely used as one of the most preferred choices for various types of operations. Robotic MIS represents the most fascinating opportunities in the area of modern diagnostic and therapeutic possibilities in robotic surgery. The need to detect various tactile properties justifies the key role of tactile sensing which is currently missing in MIS[13, 14]. In a research in 2004 which employed the finite element method, the experimental results of a tactile sensor made of a PVDF membrane were investigated, and the results of finite element method verified the data of the experiment[15]. In a recent study, a new method for determining the compliance of various objects with different mechanical properties is presented [16]. Two theoretical approaches are employed in this work. The first approach is a closed-form formula and the second one is based on finite element analysis, which is applied to the objects with complex irregular shapes. They managed to measure the stiffness of the sensed objects with reasonable accuracy (an error of about 20%). Comparing the experimental data with the analytical

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and the numerical approaches proves that there is a good correspondence between the two methods.

In this paper, using a three-dimensional model instead of a two-dimensional one, which was used in the previous research activities and studies, we improve the nodule detection and the estimation of some of its properties. Here, we employed a comprehensive numerical approach and considered all effective parameters involved in this problem. In addition to the numerical approach, a novel tactile device was designed to perform a number of experiments and the validation of the results was surveyed. The results of this investigation can be directly applied to the incorporation of tactile sensing in artificial palpation, which is demonstrated by the experiments.

MATERIALS AND METHODS

Definition of the Problem: In each application of tactile sensing, physical contact between a tactile sensor and an object is very important[17]. In this physical contact, with due attention to the design of sensor, one of the parameters of contact is used as the criterion of measurement or a factor for sensor stimulation. The factor can be load, pressure, roughness, stiffness or softness, but this factor must appear on the surface of the object where the sensor touches the object, otherwise it would not be a suitable factor in tactile sensing. In fact, the type of applications and the type of objects to be contacted have been the main motivations behind designing a variety of tactile sensors. Interaction of the sensor and tissue affects the surface of contact. These effects including stress, strain, temperature and so forth, state the situation of the tissue.

In many diagnostic tests such as Clinical Breast Examinations (CBE), doctors routinely examine the patients' body with the fingers and palm to get information on conditions inside the body such as the presence of a tumor and its precise characteristics. Thus, the subject of this research is to investigate the effects of the presence of an embedded object in the simulated biological tissue using theoretical and practical approaches.

Model of the Problem: According to the physical standard for the soft tissue simulation [18], a cube with a stiffer object inside it was chosen as a simplified model for the tissue and tumor, respectively.

The following 6 parameters called "Input Parameters" are defined:

1- Tissue loading (compression of the upper surface of the cube) (*l*)
2- Tissue thickness (*t*)
3- Tumor diameter (*d*)
4- Tumor depth (*h*)
5- Stiffness ratio of tumor to tissue (*Er*)
6- Tumor shape (*s*)

Fig. 1 shows the transversal section in the middle of the model with Input Parameters.

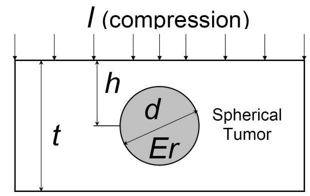

Fig. 1: Transversal section with Input Parameters.

The biological tissue and tumor are assumed to be elastic and isotropic. The elastic modulus of the tissue and the Poisson's ratio of the tissue and tumor are 5 kPa, 0.49, and 0.3, respectively [19]. Since many of the biological tissues demonstrate nonlinear mechanical properties, we have chosen different stiffness ratios by varying the value of tumor stiffness [20].

Finite Element Modeling and Boundary Conditions: This problem is modeled and solved by the ANSYS software (Release 10.0). Considering the Input Parameter ranges shown in Table 1, and the tumor shapes including sphere, oval, block and torus, the dimensions of the cube are selected large enough, in consequence of deformation. The common surface between tissue and tumor is glued to each other in order to keep continuous strain in consequence of deformation. The model has been meshed with SOLID 92 (3-D 10-Node Tetrahedral Structural Solid), and the regions near the tumor where estimated to have intense gradient of stresses are meshed with finer elements than those of other places.

Table 1: Ranges of Input Parameters.

l (mm)	*t* (cm)	*d* (cm)	*h* (cm)	*Er*
3	4	0.5	1.5	10
4	5	1	2	20
5	6	1.5	2.5	30
6	7	2	3	40
7	8	2.5	3.5	50

Procedure of Making New Models: The goal is to obtain the effects of an embedded object in the biological tissue associated with the application of mechanical loading on the tissue. Then, the changes of the tissue response versus the variations of the Input Parameters will be investigated. A "code" with the general form of "*s*: *l*, *t*, *d*, *h*, *Er*" was defined which shows the value of each Input Parameter and "Sphere: *l*, 5mm; *t,* 5cm; *d,* 2cm; *h,* 2.5cm; *Er,* 30" was dedicated as the code of "base model". Any new model was constructed by changing just one Input Parameter of the base model so that it would be possible to analyze the variation of tissue response versus changes of any Input Parameters.

Finite Element Analysis Results: According to the Input Parameters in Table 1 and the procedure of making new models, a number of cases were modeled and solved by the software and two specific results were extracted from each solution. They are as follows:

1. The stress distribution on the surface of the tissue which is called "Tactile Image".
2. The "Stress Graph", which is taken on a path defined by a straight line in the middle of the upper surface of the cube from left side to the right side.

The following results can be distinguished from the Tactile Images and Stress Graphs.

- Appearing of the effects of an embedded object on the surface in Tactile Images

The appearance of the symptoms of the tumor on the surface of the tissue is the most fundamental result that confirms the accuracy and reliability of the artificial tactile method. Fig. 2 shows the Tactile Image for the code: Sphere: *l*, 5mm*; t,* 8cm*; d,* 2c*m; h,* 4cm*; Er,*30 and demonstrates that applying compression on the tissue, which has an embedded object, will cause a non-uniform stress distribution to be produced at the contact surface.

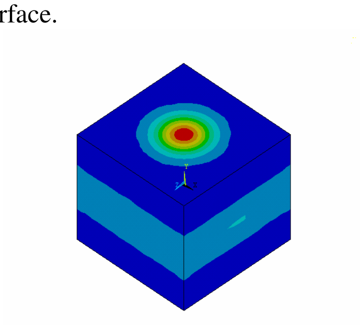

Fig. 2: Tactile Image for the code (Sphere: *l*, 5mm; *t*, 8cm; *d*, 2cm; *h*, 4cm; *Er*, 30).

- Appearing of an overshoot in Stress Graphs

In Stress Graphs, which are taken along the defined path, there is an increase (overshoot) in the amount of stress that demonstrates the tumor existence. Fig. 3 shows the Stress Graph of the base model. This overshoot of the graph, which is seen in all cases of Table 1, not only confirms the tumor existence but also locates the exact position of the tumor. This is because the position of the summit in each graph coincides with the center of the tumor in the tissue.

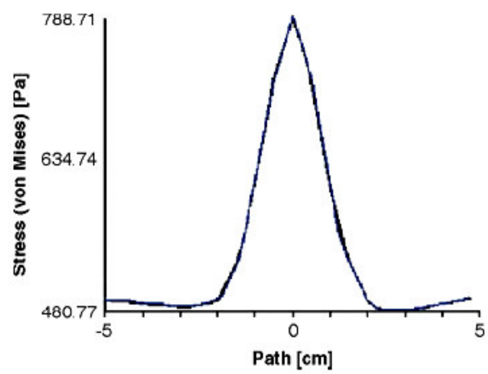

Fig. 3: Stress Graph for the base model (Sphere: *l*, 5mm; *t*, 5cm; *d*, 2cm; *h*, 2.5cm; *Er*, 30).

- Determining the tumor shape with respect to the stress distribution produced on the surface

In Tactile Images, stress contours produced on the surface of the tissue indicate the shape of the tumor. It means that if the stress contours on the surface expand circularly, then the tumor will be a sphere. Fig. 4 is related to the case when the embedded object is oval, and as can be seen, the stress contours are enlarged elliptically.

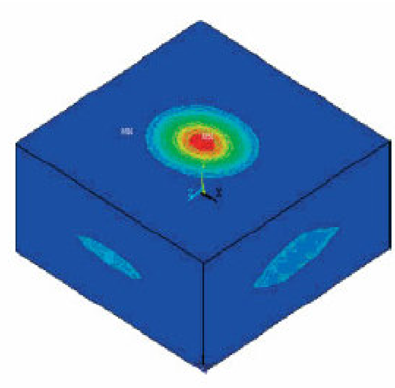

Fig. 4: Elliptical stress contours for an oval tumor (Oval: *l*, 5mm; *t*, 5cm; *d*, 4cm; *h*, 2.5cm; *Er*, 30).

- Predicting the tumor depth by using changes occurring in Stress Graphs

The schematic shape of all Stress Graphs are the same as that of the base model including an overshoot in the middle (because the tumor is in the middle of the tissue) and two decreasing parts in each side of the overshoot. Yet, variations of some Input Parameters can change this schematic shape of graphs. And it is possible, in an inversion analysis of graphs, to determine the related parameter of the tumor. The tumor depth can be one of these parameters.

Fig. 5 shows the Stress Graphs for different values of the parameter *h* from Table 1, altogether. It can be seen in the graphs that by increasing the tumor depth, the decreasing parts of the graphs become smaller and finally they disappear.

Therefore, the presence or absence of the decreasing parts of the graphs indicates low depth or high depth of the tumor, respectively.

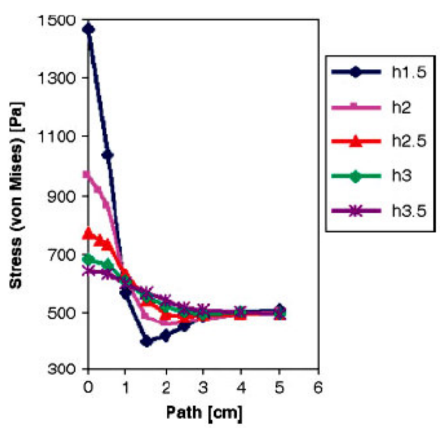

Fig. 5: Disappearance of decreasing parts of the Stress Graphs by increasing the value of the parameter *h*.

Having solved all cases of Table 1 and analyzed their Tactile Images and Stress Graphs one by one, variations of tissue response according to the changes of Input Parameters were investigated. This was conducted by mapping the maximum stress on the Stress Graphs. The new graphs are called "Tactile Map".

Fig. 6 shows the Tactile Map in which the maximum stress in Stress Graphs versus tumor depth is plotted. It is expected that the deeper the tumor, the lower the stress will become. Fig. 7 shows the Tactile Map where the maximum stress in Stress Graphs versus tumor diameter is shown. The results obtained in this research demonstrate the enhancement of the maximum stress due to an increase in tumor diameter. Fig. 8 shows the Tactile Map in which the maximum stress in Stress Graphs versus stiffness ratio is presented. Although at first the maximum stress increases, the rate of increment gradually decreases.

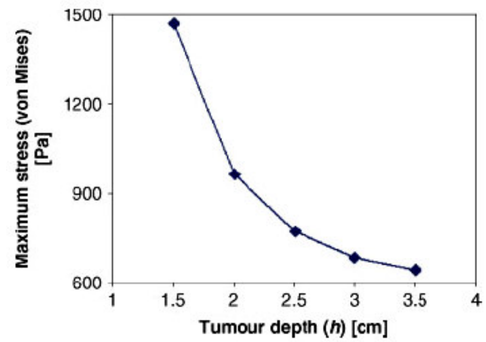

Fig. 6: Tactile Map of maximum stress vs. tumor depth

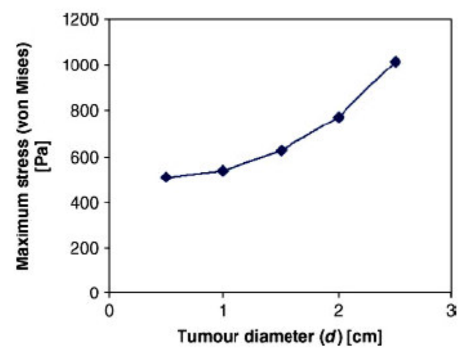

Fig. 7: Tactile Map of maximum stress vs. tumor diameter.

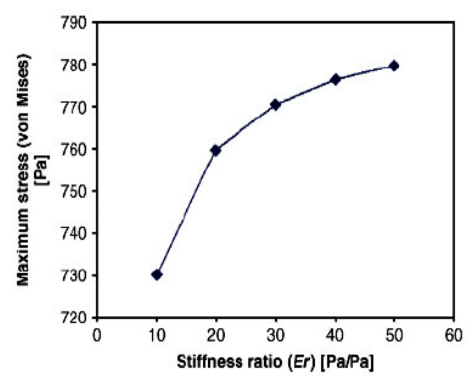

Fig. 8: Tactile Map of maximum stress vs. stiffness ratio

Tactile Tumor Detector Device Design: In order to validate the results obtained by the numerical analysis of the finite element method, we built a system, named *Tactile Tumor Detector*, which works according to Fig.

9. This figure shows the main components of this device and the flowchart of data circulation in it.

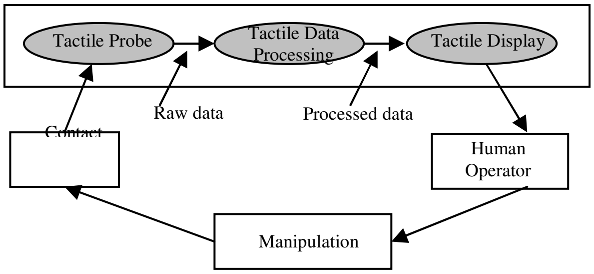

Fig. 9: Components of the *Tactile Tumor Detector*

The main part of the tactile probe, which can be easily handled, is a force sensing resistor (FSR) (Interlink Electronics, Camarillo, CA). FSRs are a polymer thick film (PTF) device which exhibits a decrease in resistance with an increase in the force applied to the active surface. Its force sensitivity is optimized for use in human touch control of electronic devices. This quality makes this kind of sensor appropriate to be used in tactile sensory systems that deal with the special configuration of forces. The sensor is placed on a dome-like probe to provide effective contacts.

The FSR is connected to an electronic board, which is the processor of the system. The prepared Op-Amp in the board converts changes in resistance to changes in voltage that is suitable to be processed by other electronic devices.

An AVR microcontroller (ATMEGA32) has been selected to receive the sent data from Op-Amp. The output of Op-Amp is connected to an analogue to digital converter (ADC) of the microcontroller. The internal ADC of the AVR decreases the amount of necessary hardware of the electronic board. To supply a suitable and accurate reference voltage for the ADC, a sensitive voltage regulator chip (LM317) accompanied by a sensitive multi-turn for its settings has been used. The microcontroller prepares received data from the FSR to be sent to a tactile display system. The tactile display system is designed by using MATLAB 7.1 software. The data are transmitted between the electronic board and the computer via the serial port.

On the other hand, we constructed a number of models to simulate a tumor in the tissue by using a typical gel containing an alien object. Then, we scanned the model by the tactile probe on a straight line passing over the tumor on the surface of the model. Fig. 10 shows the tactile sensing system with one of the constructed models.

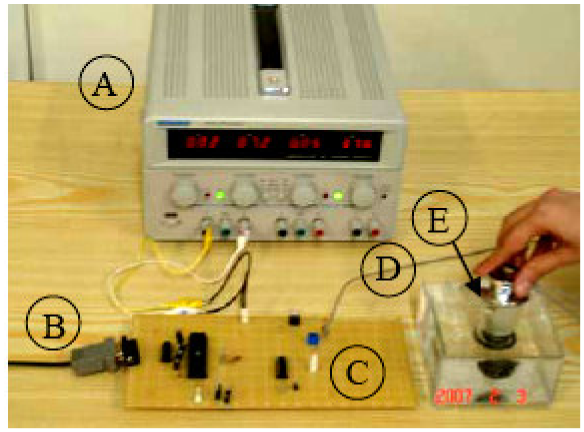

Fig. 10: Experimental setup: A- power supply, B- serial port, C- electronic board, D- simulated tissue and tumor, E- tactile probe.

Experiments Procedure: In order to perform the experiments consistently, we defined a procedure; this procedure simulates the physical examinations that a physician executes during clinical breast examinations (CBE). After that, the tactile probe is held by the user and the surfaces of the simulated models are touched by the tactile probe on a straight line passing over the alien object. This straight line is equal to 10 cm from one side to the other side of the simulated model, and the user is free to make an arbitrary number of contacts between the probe and the surface. In each contact, the user should try to apply a constant compression and then consider the response of the *Tactile Tumor Detector* on the monitor of the computer.

RESULTS AND DISCUSSION

Experimental Results: Fig. 11 shows the result obtained by performing an experiment on one of the constructed models with a spherical simulated tumor. This simulated tumor is placed near the surface of contact (small *h*).

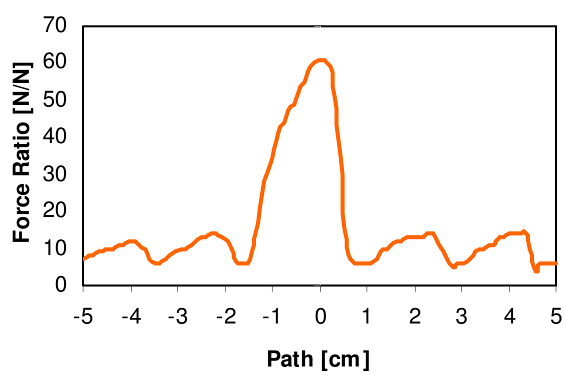

Fig. 11: Experimental result for a model with small *h*.

The horizontal axis measures the straight line that the tactile probe has followed. Intentionally, it is shown from -5 cm to 5 cm to be the same as the Stress Graph depicted in Fig. 3. The vertical axis is the processed outputs of the FSR which is proportional to the force applied by the surface of the constructed models to the active area of the FSR.

The following results can be elicited from Fig. 11:

- The presence of a tumor inside the tissue

This figure indicates that the user has performed five contacts by the tactile probe since there are five peaks, but the summit of one of them is considerably higher than that of the other ones. This event clearly denotes that the tactile probe has received more stresses that originate from the presence of a stiffer object beneath the surface.

- The location of the tumor inside the tissue

In addition to the prediction of the presence of the tumor, the *Tactile Tumor Detector* can locate the tumor. The summit of the maximum peak is obtained exactly when the tactile probe makes contact with the surface straight upon the tumor. For example, in the experiment that led to the result shown in Fig. 11 the tumor is in the middle of the constructed model since the summit coincides number zero cm.

In addition to the presentation of the results demonstrated in Fig. 11, the tactile display of the designed system provides us with another useful portrayal of the results which is shown in Fig. 12.

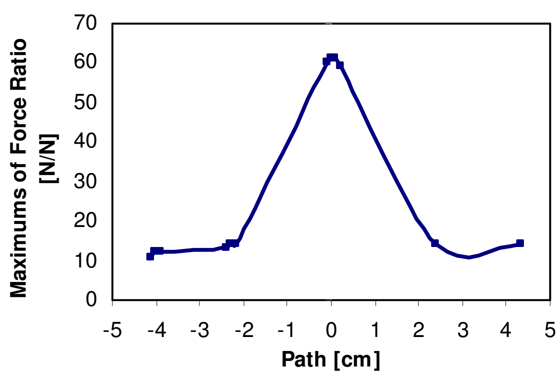

Fig. 12: Maximum value presentation of the contact results

The horizontal axis of this figure is the same as that of Fig. 11 but the vertical axis is changed. In fact, in this figure, only the maximum values which are sensed by the FSR in each contact are shown. By this method, the ascending and descending parts of each peak are eliminated. Fig. 12 is obtained from the same experiment as that of Fig. 11. This advantage of the tactile display of the *Tactile Tumor Detector* is more effective when the number of contacts is high and they cause a lot of peaks to appear beside each other.

Another situation, for which this kind of portrayal of the results is useful, is when the difference between the value of the maximum peak and that of the other peaks is small. Such a situation is illustrated in Fig. 13.

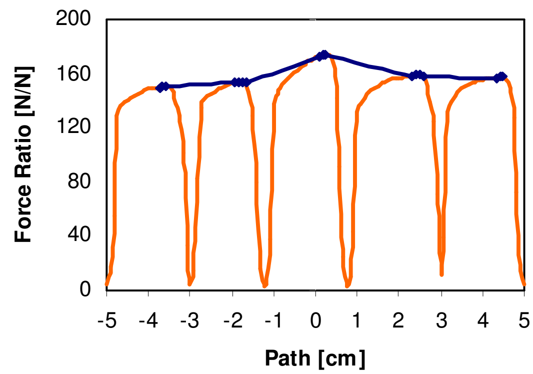

Fig. 13: Experimental result for a model with large *h*.

The experiment leading to the result shown in Fig. 13 was applied on one of the constructed models with a spherical simulated tumor placed far from the surface of contact (large *h*). This model of the experiment is in contrast with the model used to obtain the result shown in Fig. 11 since the former has small *h*. The comparison between the results of these two experiments with different values of *h* demonstrates that when *h* is large the difference between the value of the maximum peak and that of the other peaks is low and on the other hand, when *h* is small the difference between the value of the maximum peak and that of the other peaks is high. This relation helps the user to estimate the depth of the tumor which is critically important for physicians to correctly distinguish the situation of patients.

CONCLUSION

The present paper proposes an analysis on effective parameters of artificial tactile sensing by using the finite element method. The reliability and accuracy of the deformation and stress analysis are proven in order to sense the presence of a tumor in the tissue using Tactile Images and Stress Graphs.

A significant and discriminating aspect of this study is the three-dimensional analysis of the tissue and tumor. This is because performing modeling in a three-dimensional mode is the only way to observe and examine the stress contours produced on the surface of the tissue that, in turn, are used to approximate the shape, size and depth of the tumor.

Another important feature of this research is the invention of the *Tactile Tumor Detector* which is a novel device for the integration of the tactile sensing in artificial palpation. Moreover, the comparisons of the numerical results and experimental data obtained by using this novel system show accuracy and reliability of the results.

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