

## A Novel Tactile Sensor for Palpation of Breast Cancer

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**Abstract.** This paper reports the development of a novel tactile sensor evaluating tactile properties of biological soft tissues for the purpose of palpation of breast cancer. Both PVDF (Polyvinylidene difluoride) film and PSCR (pressure sensitive conductive rubber) are used as sensitive receptors in the sensor. The sensor is driven by a vibrator to apply an oscillatory stress to the object to be evaluated. Both time-domain and frequency-domain parameters of the sensor output are used for the evaluation of the tactile properties of the object. The sensor system was testified using a palpation model of breast cancer. Experimental results show that it is possible to discriminate pathological tissue from normal tissue using the sensor.

### 1. Introduction

According to statistical results, cancer has become the number one cause of death in Japan in recent years. As for the female, the incidence rate of breast cancer was the highest and the mortality of breast cancer was the fifth highest in 2014 in Japan [1]. With the progress in public health welfare and medical science, routine screening often leads to early detection and early diagnosis of breast cancer, and as a result, leads to complete healing. However, because of worries of physical pain, financial cost, etc., the breast cancer screening rate of women aged 40-69 years old is still very low, less than 35% in Japan [1]. Palpation, that is, examining tactile properties of the body by touching it, plays an important role as a simple method for early detection of breast cancer, both in clinic and at home. However, palpation depends greatly on experience, skill and subjective judgment of the examiner. Therefore, palpation sensors that can objectively examine the tactile properties of the body independent of the examiner are in demand.

In the past decades, many kinds of tactile sensors were developed, some of them have been successfully applied in the robotics field [2, 3, 4]. In biomedical engineering field, tactile sensors that evaluate elasticities of biological tissue for application of surgery robots or cancer diagnosis were also reported [5, 6, 7]. However, all those sensors measure elastic property of the objects by measuring the stress, the deform and by making use of the relationship between the stress and the deform. However, tactile properties of biological soft tissue include not only elastic property, but also viscoelastic property, which is very complicated and not yet well-studied.

Taking these into consideration, in this paper, aiming at palpation of breast cancer, we propose a tactile sensor that makes use of plural smart materials as sensing receptors. Both time-domain and frequency-domain parameters of the sensor outputs are defined to describe the complicated tactile properties of biological soft tissue.

## 2. Method

### 2.1 Sensor Structure

Two kinds of smart materials are used as the sensitive receptors in the sensor. One is PVDF (Polyvinylidene difluoride), which is a piezoelectric polymer. The other is PSCR (Pressure Sensitive Conductive Rubber). The response characteristic of PVDF is similar to the human tactile sensitive receptor Pacinian corpuscle or Meissner's corpuscle, which respond to the rapid change of brief tactile signals, while the response characteristic of PSCR is similar to the human tactile Merkel disk or Ruffini ending, which respond to persistent tactile signals. Figure 1 shows the structure of proposed sensor. The sensor takes a layered structure, and is stacked on a metal sensor base. At the top of the sensor head is a layer of silicon rubber with the size of 10 mm x 10 mm x 2 mm (length x width x thickness, same later). Under it is a sheet of PVDF film (DT1-28, 10mm in diameter, 40 $\mu$ m in thickness) wrapped in surgery gauze. Under the PVDF film and gauze is a layer of acrylic board (10 mm x 10 mm x 5 mm), Further under the acrylic board is the PSCR (SF-5-LT, 8 mm x 8 mm x 1 mm), which is sandwiched between the acrylic board and the metal sensor base. By using PVDF and PSCR as sensitive receptors at the same time, simultaneous detecting of rapid and slow tactile properties is expected.

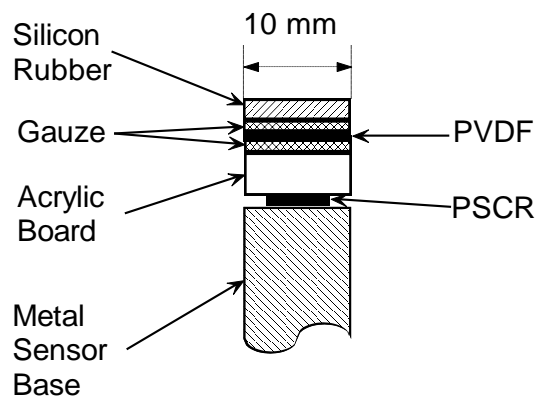


Fig. 1. Schematic Structure of Proposed Sensor.

### 2.2 Experimental Setup

The sensor was first tested with soft samples made of soft silicon gels that are used for making phantoms of human organs or epithese of human parts, and then verified with a breast cancer palpation model. Experimental setup is shown in Fig. 2. As shown in the figure, the sensor is fixed up-side-down to a vibrator that drives the sensor vertically in sinusoidal waveform with a specific amplitude of 1.5mm and at a specific frequency of 7Hz, which were determined empirically from the result of the previous experiments [8]. During experiment, the sensor head applied an oscillatory stress in sinusoidal waveform to the object (sample) placed under it.

Output of the PVDF was connected to a charge amplifier (4001B, Showa Instrument Co.) and output of the PSCR was first connected to a self-made signal conditioning circuit and then to an amplifier (P-61, NF Co.). After being conditioned and amplified, the two outputs were recorded by a data recorder (EZ7510, NF Co.) at sampling frequency of 1000 Hz and then transferred to computer for further analysis.

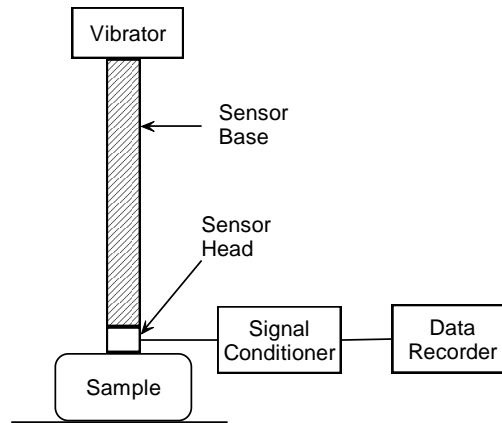


Fig. 2. Experimental Setup.

Time domain parameter  $p_1$  that describes the strength of the sensor output was defined in Eq. (1) as below:

$$p_1 = \frac{1}{n} \sum_{i=1}^n |x_i| \quad (1)$$

where  $x_i$  is the  $i$ -th sampled data of sensor output  $x$ , either PVDF or PSCR.

Frequency domain parameter that describes the deformation of sensor output waveform from the sinusoidal waveform was defined as

$$p_2 = \frac{a}{b} \quad (2)$$

where  $a$  is power component inside the frequency band covering the primary frequency of power spectrum of sensor outputs, and  $b$  is the power component included in the frequency band range from primary frequency up to the 5th harmony of the power spectrum of sensor outputs. This parameter reflexes hysteresis behavior of sensor outputs caused by viscoelasticity of the object.

### 2.3 Experimental Samples

Silicon gels of three different hardness were used to test the sensor. They are gel #0, which is similar to fat, gel #5, which is similar to muscle, and gel #15, which is similar to tumor. The sensor was also tested with a sample that was made of gel #5, with alien substance (copper wire) implanted at deferent depth.

Laboratory verification of the sensor was further carried out using a breast cancer palpation model (M44, Kyoto Science), which is used for medical student training. Beside normal part of breast, there are four kinds of abnormal symptom in the model. They are: A, a cancer with the dimple symptom; B, a cancer with skin depression; C, fibromatosis; and D, mastopathy. The experimental setup was the same as in the previous research. Measurements were done five times at the position of the four abnormal sites and one normal site, each measurement lasted for 10 seconds.

### 3. Results and Discussion

Experimental results using the gel samples was reported previously, therefore will not be described here in details [8]. The results can be summarized briefly as: outputs of PVDF and PSCR

depend on both the hardness of the samples and the thickness of them.  $p_1$  of PVDF and PSCR outputs has a strong correlation with hardness and thickness while  $p_2$  has a weak correlation with the thickness of the sample. Therefore, it is difficult to measure the tactile properties of *in vivo* soft tissues with one single parameter. However, our preceding research also showed that by combinatory using of the parameters, it is possible to evaluate the tactile properties of the soft tissue, and to discriminate different objects. Experimental results of preceding research also verified that the sensor can successfully distinguish the presence of the alien substance in the objects [8].

Figure 3 shows the results of the verifying experiments using the breast cancer palpation model. Scattering of  $p_1$  of PSCR measured at A, B, C, D and normal part of the model vs. those of PVDF are plotted in the left, and those of  $p_2$  are plotted in the right. In the figure, dots refer to means of parameters and error bars refer to standard deviation of them. From the left figure one can notice that using  $p_1$  of PVDF, it is very easy to discriminate B from others. However, it is difficult to discriminate D, A, C and normal from  $p_1$  of PVDF. While from  $p_1$  of PSCR, even though it is difficult to discriminate B and A, it is easy to discriminate D, group of A and B, and group of C and normal. By using  $p_1$  of both PVDF and PSCR, it is easy to discriminate A, B and D, however, it is difficult to discriminate C from normal part, especially from  $p_1$  of PSCR, it is impossible to tell the difference between C and normal part. On the other hand, from the right figure, though it is difficult to discriminate C and normal part from  $p_2$  of PSCR, it is quite easy to discriminate them from  $p_2$  of PVDF. Using classification method such as multi-dimensional support vector machine, it is quite easy to discriminate all the abnormal symptoms with parameters  $p_1$  and  $p_2$  calculated from the outputs of both PVDF and PSCR.

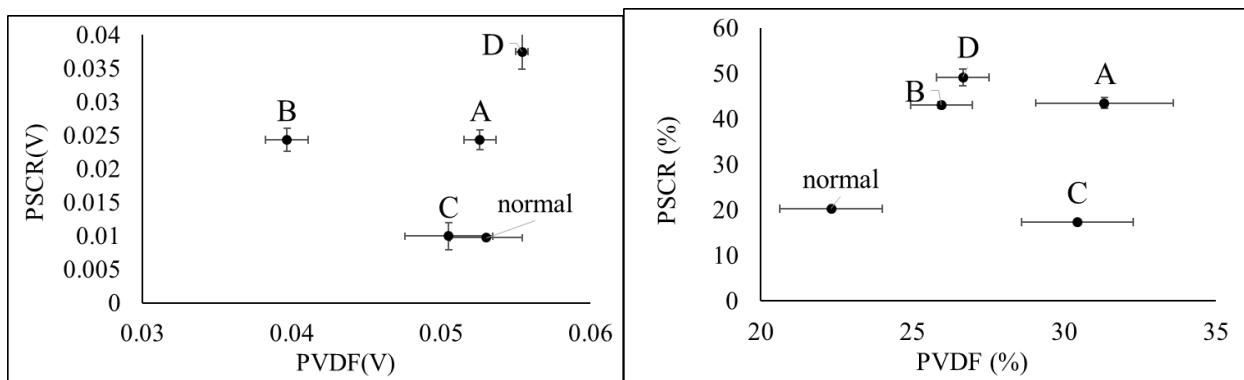


Fig. 3. Experimental Results. Left:  $p_1$  calculated from PVDF and PSCR; right:  $p_2$  calculated from PVDF and PSCR. Dots refer to the mean and error bars refer to standard deviation.

#### 4. Conclusion

In this study, aiming at early detection of breast cancer, we developed a tactile sensor for palpation of breast cancer. Both PVDF and PSCR are used as sensitive receptors in the sensor. Time-domain and frequency-domain parameters of the sensor output are defined for the evaluation of the tactile properties of the object. The sensor was verified using a palpation model of breast cancer. Experiment results verified that it is possible to discriminate abnormal tissues from normal tissue using the sensor. Further works in improving the sensor, especially in the driving vibration mechanism and down-sizing of the sensor is underway. The sensor should also be further tested with real biological tissue through animal experiments and clinical experiments before its application.

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