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Research Article

Analysis of Piezoresistive based MEMS Tactile Sensor for Human Skin Heat Condition

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Abstract

The major requirement of implantable biomedical equipment like pacemaker, hearing aid device must have low power consumption and reliability. In order to provide a power to this biomedical equipment's a new approach is presented in this paper, to extract electric power from heat of the subject or human body. Hereby the surgeries for battery implantation in the subject or human body can be avoided. The electrical power is extracted from human skin using a tactile sensor which is made adaptable to thermal changes in skin, this cause a change in potential thereby change in displacement results in change its piezo-resistance which causes change in potential. This change in potential can be stored in a battery of the biomedical equipment and then the battery will supply the source to the biomedical equipment. This tactile sensor is mounted at or near the contact interfaces mainly the skin and deal with the data from localized regions. A tactile sensor is designed as a rectangular plate with suitable materials like PI and Si_3N_4 provided with its own material specification and simulated based on MEMS technology. The piezo electric resistor is made of NiCr alloy which provides a better corrosion resistance thereby the life time of tactile sensor can be improved.

Keywords: *Polyimide, MEMS, Piezo-electric Devices, Tactile Sensor, Skin*

1. Introduction

MEMS based thermal conditioning tactile sensor array design analysis and fabrication for bio-inspired application is presented. A numerous researches have been carried out in the area of tactile sensing and various transduction methods have been explored. However, currently no device exists to measure the thermal changes in skin and to extract electric power from human skin by using a biological tactile sensor.

The goal of this paper is to extract electric power from human skin using mems tactile sensor. This tactile sensor is made adaptable to thermal changes in skin**.** In general this tactile sensor is adapted over the surface of human skin. A small change in temperature in skin causes this tactile sensor to change its piezo resistance and this causes a change in potential and can be stored in a battery. Here the tactile sensor is designed and simulated using comsol multiphysics software and this tactile sensor is then made adaptable to change in temperature and thermal stress. This harvested energy can then be used in medical implantable devices like artificial pace maker, hearing aid device; thereby the battery replacement in such implantable devices can be avoided. Several researchers have developed piezoresistor-based flexible tactile sensors with linearity, force sensitivity, and dynamic range appropriate for their particular applications. Some of the earlier work includes silicon-based piezoresistive and capacitive micro sensors relying on the principle of force-sensing elements with diaphragms or cantilevers (Rohit Kilaru et al, 2013). But to our knowledge this is the first time, a piezoresistor based NiCr film is subjected to thermal changes and change in displacement is noted and thereby maximum stresses is applied over piezoresistors, due to resistance mismatch and due to inverse piezo electricity conditions potential is made to develop over sensor interface.

The tactile sensor is a device which measures the parameters of a contact between the sensor and an object. This interaction existence is confined to a small defined region. Tactile sensor is used for the detection and measurement of spatial distribution of forces perpendicular to a predetermined sensory area, and the frequent interpretation of the spatial force information. A tactile-sensing array can be considered to be a coordinated group of touch sensors.

A tactile sensor consists of an array of touch sensitive sites; the sites may be capable of measuring more than one property. The contact forces measured by these sensors are able to convey a large amount of information about the state of a grip.

2. Design Methodology

In tactile a NiCr piezoelectric resistor is placed in a flexible polyimide layer (Rohit Kilaru et al, 2013). The purpose of using polyimide material is that it protects the

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sensor and the connecting circuit; also it distributes the force, converting the force sensors on the micromachined membrane to tactile sensors. Finally, it allows the placement of the sensors on a minimal strain plane, such that flexibility of the entire system does not damage the sensors (V. Shamanna et al, 2006). NiCr serves as a high temperature corrosion resistant. The tactile sensor 3D layout was developed form a 2D model and processed in comsol multiphysics. Mesh generation was performed by setting the mesh setting to the model, a free triangular mesh is mapped on the tactile sensor geometry (Takahiro Namazu et al, 2007).

The piezoelectric resistors arranged in the form of half Wheatstone bridge configuration; this causes a difference in potential due to displacement changes in the tactile sensor. This displacement is due to change in temperature developed over the skin which heats the tactile sensor and this heating, bends the tactile sensor like a cantilever beam, therefore displacement occurs due to heating and this causes change in resistance, thereby a potential is developed (H.-K. Lee et al, 2008). This change in potential is very low so a signal condition unit is maintained to amplify the signal thereby it can be used for further applications.

2.1 Geometry of tactile sensor

Tactile sensor is designed with rectangular plate of width 150 µm and height 60 µm. The NiCr material is specified circle of radius 10 µm. The heat flux is designed with width of 150 µm and height 5 µm. This NiCr material is connected to the heat flux with the help of PI (Polyimide) material of width 15 µm and height 5 µm. The materials are properly specified and the model is applied to each domain accordingly.

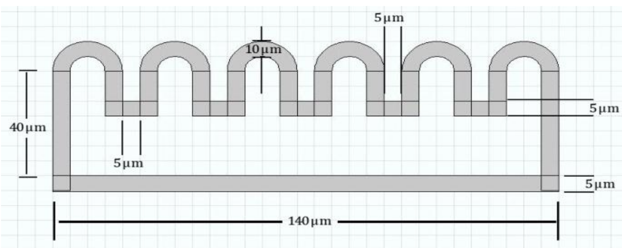

Fig. 1 Geometry of Tactile Sensor without Superstrate

During the analysis part, the thermal stress applied to the sensor through Thermal Stress (ts) model and the change in potential is measure with Piezoelectric Device (pzd) model. In thermal stress model, a suitable heat flux is applied to the sensor through a fixed plate and this thermal change makes the substrate to get deformed. Once if the substrate gets deformed, the Wheatstone bridge moves along with the substrate. This movement of the resistors causes the potential to be created between the top and bottom plate of the heat flux.

Thus the sensor is designed with its proper specification all the physical property values are specified which is most important one in the design progress. When thermal changes are applied to the tactile sensor through the skin, the heat flux makes the NiCr to a state of deformation. This deformation causes the resistors in the piezo electric resistor to change its values, where the top plate is specified as voltage potential and the bottom plate is specified with ground. This deformation causes the shape of the resistors to change.

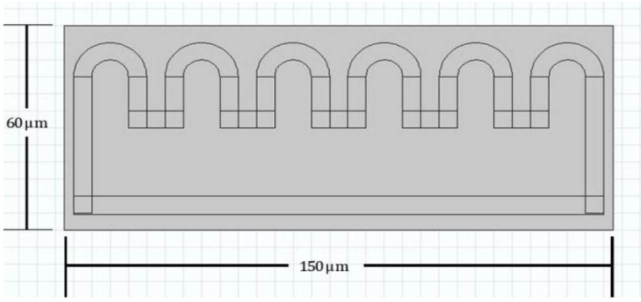

Fig. 2 Geometry of Tactile Sensor with Superstrate

This change causes a potential difference and that difference can be measured from the half Wheatstone bridge configuration (Rohit Kilaru et al, 2013). In practical case when multiple array of tactile sensor is placed a higher voltage potential can be obtained. Since only a small amount of voltage exist using a single tactile sensor.

3. Finite Element Analysis

The piezoresistive based MEMS tactile sensor model analysis is carried out to investigate and understand the thermal stress and displacement the piezoresistive MEMS tactile sensor when external an external temperature is applied. First, the model files was drawn in 2D then it is modelled to 3D structure so that there will be no error during analysis.

Then pre-processing is the second step and it is an important step in stimulating tactile sensor to such thermal conditions. Some pre-processing procedures involved during analysis of piezoresistive MEMS tactile sensor model is discussed here.

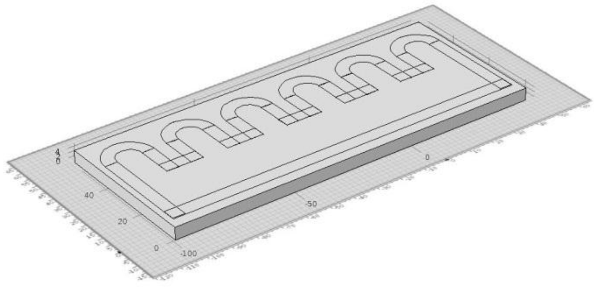

Fig. 3 Tactile Sensor Layout in 3D

3.1 Material Properties

Several types of element have been tested in order to suit the piezoresistive MEMS tactile sensor model, but NiCr is best suited because of its high temperature corrosion resistance (K. Kim et al, 2006). Linear properties are chosen because the analysis with these properties requires only a single iteration and not temperature dependent. The material properties mainly play an important role in provided the perfect elemental analysis of the tactile sensor design (see Table I). These values are taken from (Rohit Kilaru et al, 2013) as the paper has specified with NiCr film.

The material is also defined as isotropic which means the same mechanical properties are applied in all directions. NiCr material is used during fabrication of piezoelectric based mems tactile sensor (S. U. Jen et al, 2003).

Table I Material Properties for Tactile Sensor

Property	**NiCr**	**PI**	**Si_3N_4**
Young's modulus[GPa]	18.6	7.5	30.4
Poisson's ratio	0.38	0.35	0.24

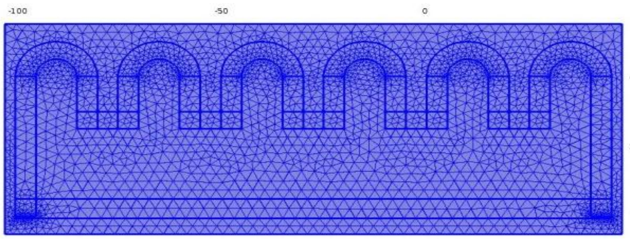

Fig. 4 Meshed Elements over Sensor Substrate

Other flexible materials like Si_3N_4 and PI are used because of its flexible nature (Rohit Kilaru et al, 2013).

4. Simulation and Result

In result the data solutions are set to solver 1 and model 1. The solver solves the values using the equations which are already inbuilt in the software for each model. Also multiple plots can be obtained for various functions. Here three plots are obtained for stress (ts), temperature (ts), potential (pzd).

4.1 Stress: Development of stress due to change in temperature in tactile sensor, this change in temperature causes deformation in the tactile sensor which moves upwards and downwards over the contact surface, this change in stress is shown (D.J. Lichtenwalner et al, 2007).

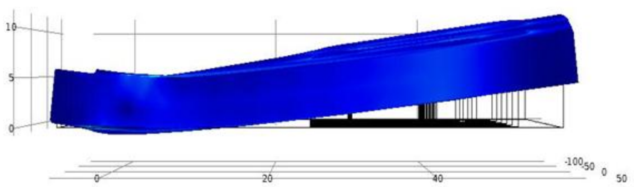

Fig. 5 Side View of Stressed Tactile Sensor

4.2 Temperature: When the material is subjected to change in temperature due to the temperature change in contact surface. This displaces the sensor and thereby piezoresistors undergoes average stress and average strain (Rohit Kilaru et al, 2013). The temperature is given according to human skin conditions which range from 96˙C to slight higher temperature up to 100˙C.

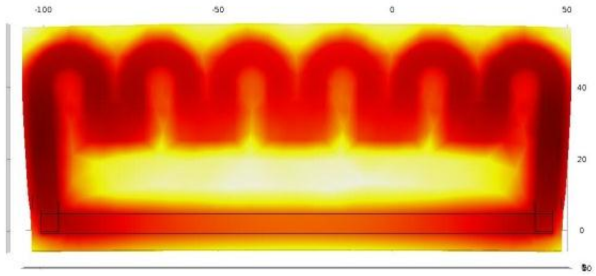

Fig. 6 Stressed tactile sensor with change in temperature

4.3 Potential: Temperature is applied over the sensor based on human temperature changes a parametric sweep values ranging from 96˙C to 100˙C is provided such that change in displacement causes nichrome piezoresistor to change its values, thereby a potential developed over the sensor interface and the resultant voltage is plotted along with displacement [see Fig. 10].

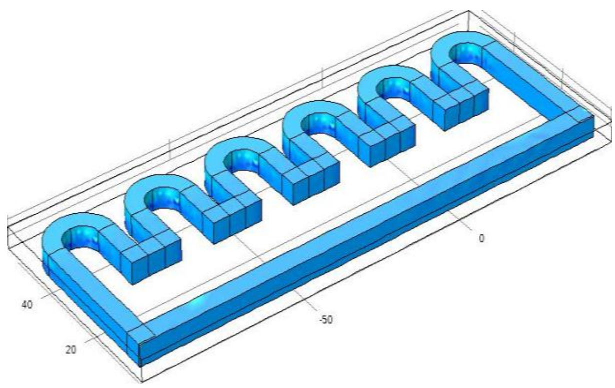

Fig. 7 Potential developed over sensor interface

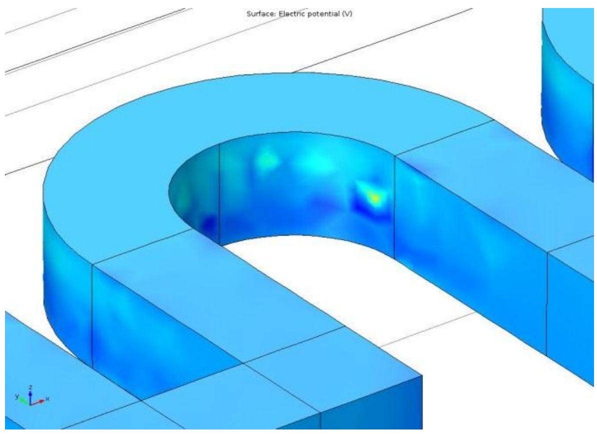

Fig.8 Potential developed (Zoomed View)

5. Experimental Results

This tactile sensor is fabricated according to thermal conditions and this fabricated array of tactile sensor is placed between two metal plates such that heat from the skin can spread evenly over the array of sensor through the metal plate due to uniform heating of the metal. Spreading of heat is non-uniform over sensor array, so a uniform heat spreading device is placed over tactile sensor array and required heat is made to spread over tactile array. This material is chosen to fibre glass.

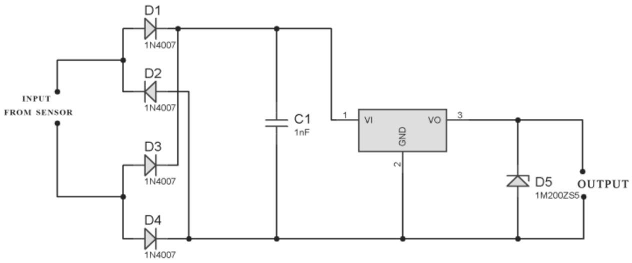

Fig. 9 Signal Conditioning Unit

This metallic plate embedded with tactile sensor is placed along with a signal conditioning unit that serves as a signal booster that increases the voltage level of the desired output from the tactile sensor array. A decoder unit is placed in between the tactile sensor and the signal conditioning unit because it has to decode the array values from the sensor to the signalling unit.

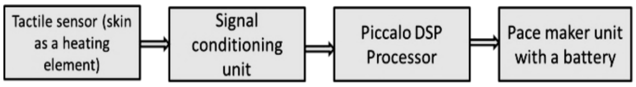

Fig. 9 Electric Power Sensing System

The boosted voltage is then given to a data acquisition unit consists of picollo microcontroller, this is chosen because of its higher optimal efficiency and increased functionality.

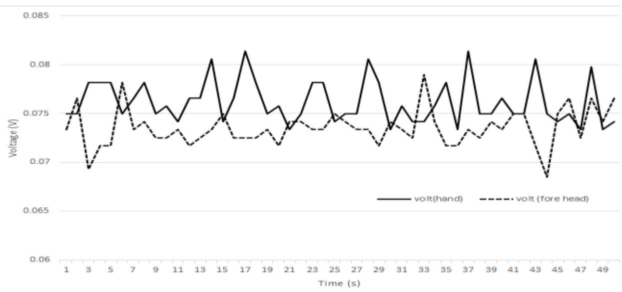

Fig. 10 voltage levels noted in hand and in forehead

This processes with much higher speed for this 32-bit array and collects the amplified voltage for greater energy efficiency. The collected voltage can be viewed in signal viewing software or to a battery operated devices like pace maker or hearing aid device. The observed results are shown in Fig. 10. The voltage levels were collected in hand and in forehead.

The following Fig. 11 shows the change of potential due to upward and downward displacement of the sensor. The upper curve shows that the sensor displaces downwards and vice versa.

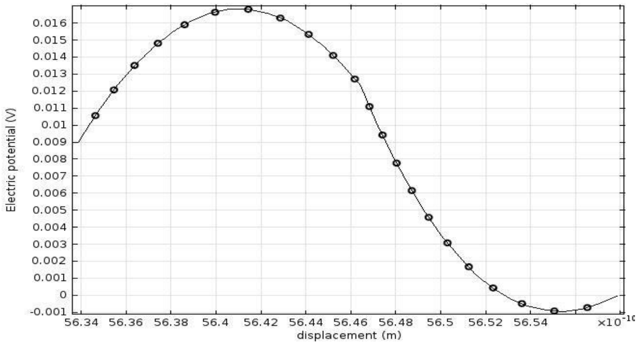

Fig. 11 displacement vs. potential

6. Conclusions

Using finite element analysis, a tactile sensor is thus been designed using comsol multiphysics. Thus the sensor is made localized over human skin temperature conditions. A change in temperature is applied over a tactile sensor using thermal stress model and the piezoelectric device model has converted the displacement changes due to thermal conditions into change in potential were observed in simulation. In this approach both models are stimulated simultaneously. The tactile sensor which was thermally stressed and the resultant displacement cause the piezoelectric resistor to obtain a voltage potential of about 0 to 0.16 microvolt. Thus by placing an array of sensors a large voltage potential can be obtained.

Further developments can be done by placing a suitable tactile sensor or an array of tactile sensors over a skin and making the sensor to adaptable for the human skin condition along with the signal conditioning unit to boost up the output potential, mainly it should be made adaptable for thermal change in skin and thereby the change in potential that develops can thus be stored in a battery which can used in medical implantable devices like cardiac pacemaker, hearing aid device. Much higher potentials can be developed for same substrates using other materials like Pb, Au piezoresistor film (Rohit Kilaru et al, 2013).

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