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# ON THE TACTILE SENSING BY USING SMART MATERIALS

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***Abstract* :** *The aim of this work is to present a virtual experiment concerning the recognizing of the shape and texture of a 3D object performed by simulation the action of an array of nanopiezotronic transistors integrated into the skin. A flexible finger with the muscles made of Nitinol wires and the skin made of auxetic material is considered. The array of nanopiezotronic transistors makes possible the detection of the pressure-induced changes in the auxetic skin. An inverse problem is solved in order to find these parameters from the condition that the n-ellipsoid best fits the set of data points probed by touch with the finger*

***Keywords* :** *Nitinol, auxetic material, tactile sensing, shape and texture*

## 1. INTRODUCTION

Robotic tactile sensing involves techniques for knowledge transfer from human to robot. The robotic tactile sensing in touching, grasping and manipulating of the objects is the base for exploring and differentiating the objects from one another with respect to shape, surface texture, stiffness, temperature etc. [1, 2].

Geometrically and structurally, the skin is a complex mechanical system supported by the deformable system of muscles and tendons. The stiffness of various skin layers significantly varies with epidermis being considerably stiffer than the dermis (the Young's modulus of base layer, i.e. the epidermis is 10–10000 times that of the dermis). Skin acts as a multilayered, nonlinear, nonhomogeneous and viscoelastic medium in order to convert the surface indentation into stress and strain fields. The thickness of skin in adult humans vary between 0.6–0.8 mm and the Young's modulus is around $4 \times 105\ \mathrm{N/m^2}$.

In order to mimic the tactile sensing capabilities of the human skin, a flexible finger with the muscles and skin made of Nitinol (NiTi) wires and auxetic material, respectively, is considered in this paper, in the spirit of the article Munteanu et al. [3]. The robotic shape detection of the objects within the contact area (7–12 mm) of the fingertip may be realized by using the interface piezotronic effect. The piezotronic effect arises as a result of the polarization of non-mobile ions in the crystal, unlike the piezoresistive effect which results from a change in band gap, charge carrier density, or density of states in the conduction band of the strained semiconductor material. Therefore, the piezoresistive effect is a symmetric volume effect without polarity, whereas the piezotronic effect is an interface effect that asymmetrically modulates local contacts at different terminals of the device because of the polarity of the piezoelectric potential [4, 5].

As mentioned above, the muscles are made of NiTi wires. The phase change in the NiTi wires is achieved by heat exchange with a heat source and a heat sink. The actuation frequency of the NiTi wires is only dependent on the rate of heat transfer with its surroundings. The heat transfer mechanism for most Nitinol wires are based on resistive heating and cooling with forced convection or natural convection. Because this is an inefficient heat exchange mechanism which requires the use of electrical power, we chose the semiconductors for which Peltier effect has shown high actuation frequency. In other words, we use the forced convection heating and cooling to actuate the NTi wires. This can overcome the low energy density resistive heating systems and the low efficiency of the thermoelectric heat transfer mechanism, even though it should need additional devices such as a pump and valves.

Conventional foam exhibits pores with an average diameter of around 1mm, while the auxetic foam has a possible average diameter of a few micrometers or even nanometers. Processing manufacturing techniques of auxetic materials can control various features of the pore shapes and is performed by a compression process [6-10].

## 2. INVERSE PROBLEM

Let us consider a flexible finger modeled as a cylindrically rod of length $L = 6$cm and radius $R = 0.5$cm, with three embedded Nitinol wires (yellow) in an aluminum matrix, at uniform absolute temperature $T_0$ (Figure 1). The NiTi wire has the length $L$ and radius $r$, and are placed in a parallel arrangement to form the vertices of an equilateral triangle. The $x$-axis has the distal direction, the $y$-axis the radial (reference) direction, and $z$-axis the tangential direction. The rod is covered with a thin layer of auxetic material (red colour) representing the skin of the finger. Both the matrix and the NiTi wires are assumed to be initially straight at $t = 0$ and $T_0 = 33^0$ C. The NiTi wires are heated above the austenitic start temperature by passing an electrical current, and the deflected beam tends to return to the initial configuration. The NiTi alloy acts as an actuator transforming electrical energy into mechanical energy, annihilating the deformed shape of the rod. Topological view of the skin with hexagonal pores and the nanowires (red circle) is shown in Figure 2.

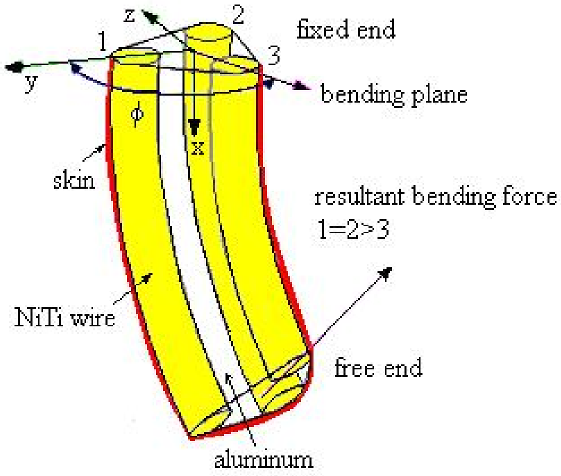

**Figure 1:** A flexible finger.

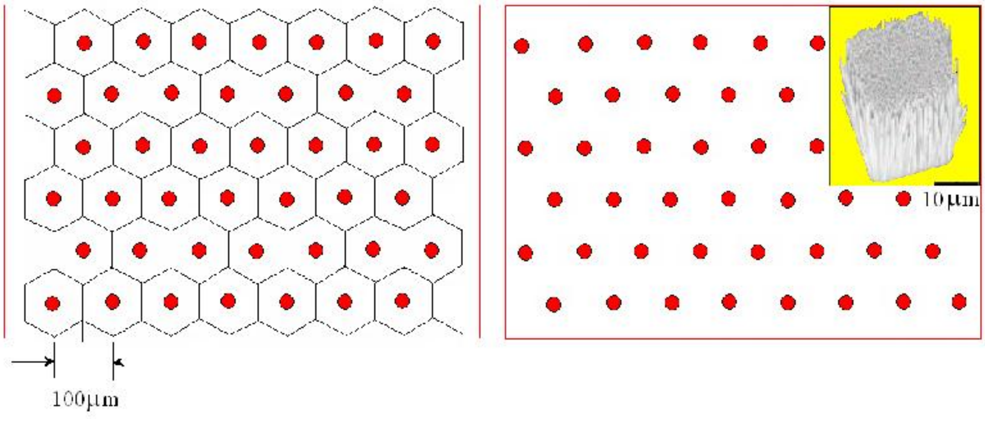

**Figure 2:** Topological view of the auxetic skin with hexagonal pores where the nanowires are positioned (red circle).

The operation of the gripper finger relies on the elastic deformation of three embedded NiTi wires (55% Ni, 45%Ti) in an aluminum matrix. Using a different force in each NiTi wire a range of extension forces causing the finger to bend according to the constraints provided by the end plate. The larger the force, the larger the resulting finger tip deflection. In addition to bending, the triangular arrangement enables the direction of fingertip movement to be controlled.

The finger motion is described by a complex set of equations containing the aluminum equations, the NiTi wires (muscles) equations, the equations of the auxetic skin coupled with the ZnO nanowires, the conditions on the interfaces between aluminum-NiTi wires, aluminum-auxetic material, NiTi wires-auxetic material, auxetic material- ZnO nanowires, boundary conditions and initial conditions. e assume that a finger is used to probe an object to detect its shape and the texture. The array of nanopiezotronic transistors makes possible the detection of the pressure-induced changes in the auxetic skin.

Although it is difficult to detect the shape of the object only with one finger, we still consider this variant for simulation the detection of the shape of objects with well-defined geometry such as balls or eggs. Instead, the texture can be detected using a single finger. To detect both the shape and texture, the finger can walk, rub and rotate on the surface of the object until a control parameter reaches a value proposed by algorithm.

## 3. RESULTS

Consider a damaged a graphite plate of length 9cm. height 5cm and thickness 1cm (figure 3). The material is strongly anisotropic and damages make the texture to contain shallows, cracks and bumps. Therefore the finger will have to touch the material along 25 arbitrary paths shown in figure 4. If results require, the path traveled by the finger will have to get thicker where the texture is difficult. The finger walks without press the surface of the object with the velocity of 1cm/sec. The surface irregularities, elevations and simples not exceed the limit of the spatial resolution of the sensor. Some arbitrary cross-sectional slices of the image of the object furnished by the inverse technique are shown in figure 5.

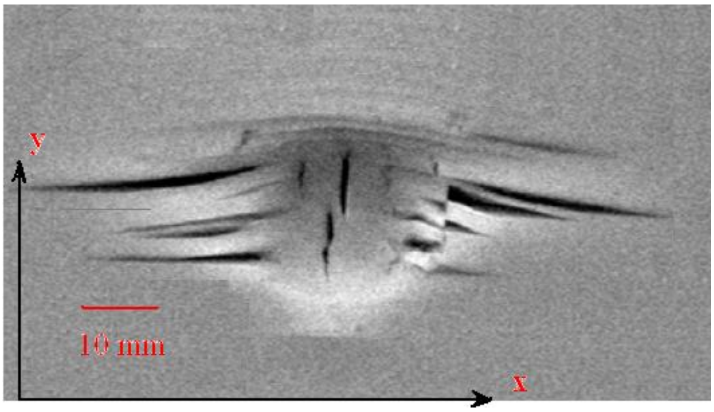

**Figure 3:** A damaged graphite plate.

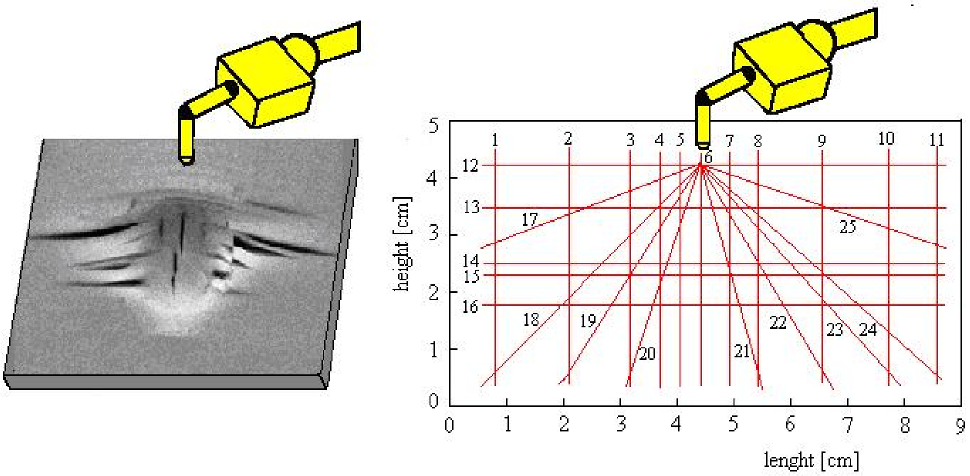

**Figure 4:** The finger tracking the plate. To the left the trajectories of the finger are shown.

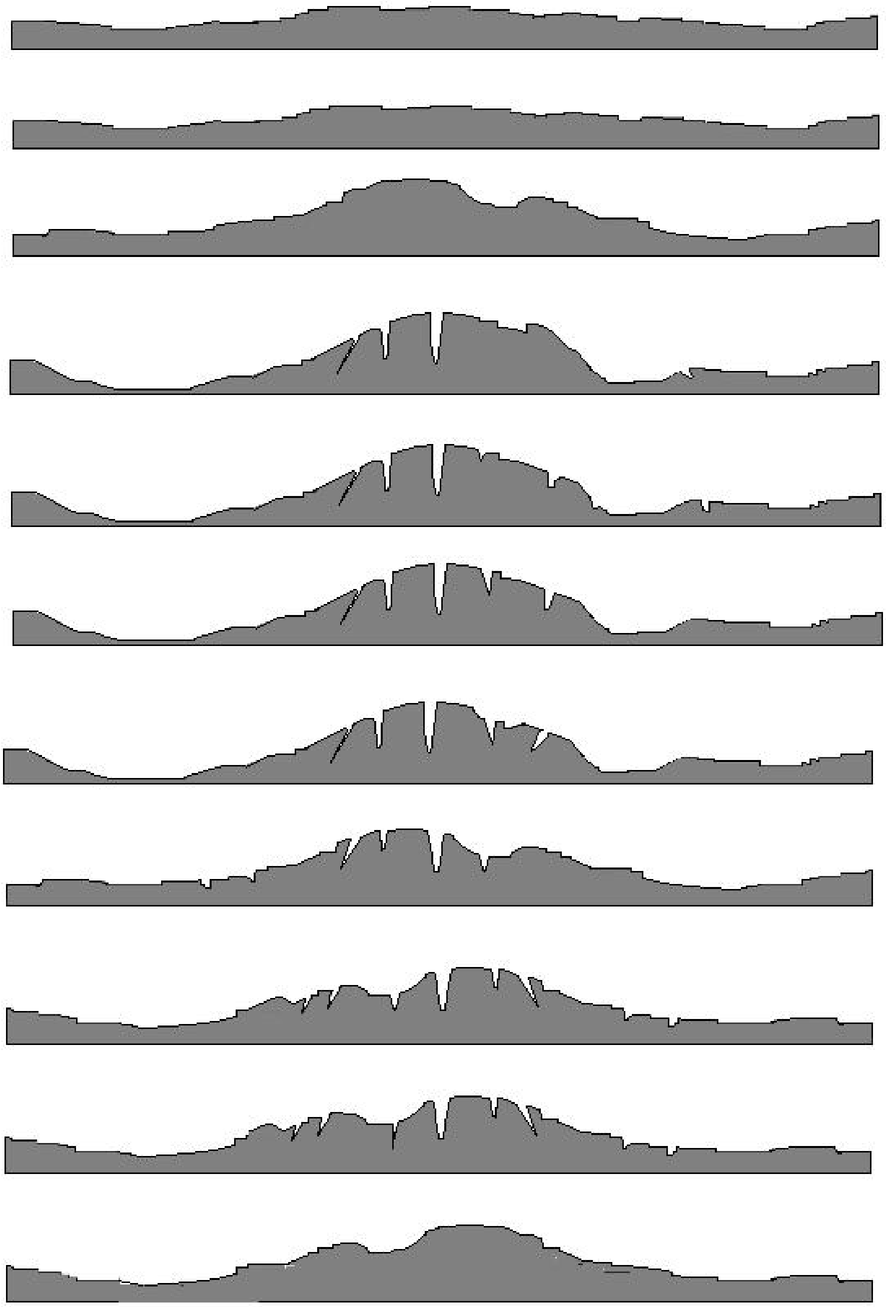

**Figure 5:** Some arbitrary cross-sectional slices of the image of the object.

## 4. CONCLUSION

The aim of this work is to present a virtual experiment concerning the recognizing of the shape and texture of a 3D object performed by simulation the action of an array of nanopiezotronic transistors integrated into the skin. A flexible finger with the muscles made of Nitinol wires and the skin made of auxetic material is considered. The array of nanopiezotronic transistors makes possible the detection of the pressure-induced changes in the auxetic skin. The shape and texture of the 3D object is best estimated by determining the surface and texture of the object as an *n*-ellipsoid defined by 12 parameters. An inverse problem is solved in order to find these parameters from the condition that the *n*-ellipsoid best fits the set of data points probed by touch with the finger.

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