

# Sensing the material by minimally invasive surgery grasper

## Abstract

Minimally Invasive Surgery (MIS) is a modern surgical technique. In MIS the surgeon should have more experienced compared to open surgery to perform a surgery by long instruments separation from the operation room. So, the surgeon has not any sense of grasping the organ as normally has in regular surgery in which the surgeon has a complete sense of touch. Thus, a less expert surgeon who wishes to perform MIS should be trained and perform open surgery for a couple of years before he/she can involve in a surgery operation. These limitations motivate researchers in biomedical engineering to explore the new smart system and design new surgical grasper. In this project we design and model a smart grasper which can sense and recognition the grasped material respect to the generated voltage, also finding the magnitude of the allowable applied force by the surgeon which does not hit the organs is possible.

**Keywords:** minimally invasive surgery, grasper, piezoelectric

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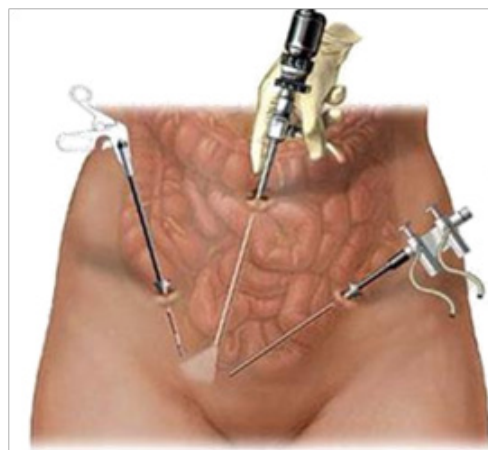
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## Introduction

Minimally invasive surgical techniques, commonly referred to as keyhole techniques, belly-button surgery, or laparoscopy, were aggressively developed in the 1990s. Minimally invasive surgery (MIS) also called Laparoscopic surgery, bandied surgery, keyhole surgery, or pinhole surgery. It is a modern surgical technique in which operations in the abdomen are performed through small incisions (usually 0.5-1.5 cm). (Figure 1). Callaghan et al.<sup>1</sup> used direct measurement of contact forces between a surgical instrument tips for scissor blades and the tissue. Tavakoli et al.<sup>2</sup> designed a robotic master slave system for use in minimally invasive surgery. The system was capable of providing haptic feedback to the surgeon in all available degrees of freedom, providing a sense of touch to the user. Sokhanvar<sup>3</sup> proposed a sensor and modeled both analytically and numerically and a series of simulations performed in order to estimate the characteristics of the sensor in measuring the magnitude and position of a point load, distributed load, and the softness of the contact object. Shikida et al.<sup>4</sup> presented an active tactile sensor with ability to detect both contact force and hardness of an object. Their system consisted of a diaphragm with a mesa (a flat-topped projection) at the center, a piezoresistance displacement sensor at the periphery, and a chamber for pneumatic actuation. Dargahi<sup>5</sup> proposed a prototype tactile sensing system with only three sensing elements. The magnitude and position of the applied force were obtained by utilizing triangulation approach combined with membrane stress. Narayanan et al.<sup>6</sup> presented the design, analysis, and fabrication of a micro machined piezoelectric endoscopic tactile sensor to determine the properties of tissues in minimally invasive surgery. Rosen et al.<sup>7</sup> developed a computerized force feedback endoscopic surgical grasper (FREG) with computer control and a haptic user interface in order to regain the tactile and kinesthetic information that is lost. The system used standard unmodified grasper shafts and tips. The first steps in realizing soft tissue models through the development of an automated laparoscopic grasper and tissue cutting equipment to characterize

grasping and cutting tasks in minimally invasive surgery (MIS) were taken by Tholey et al.<sup>8</sup> Sjoerdsma et al.<sup>9</sup> measured the force transmission of laparoscopic grasping forceps and bowel clamps and showed that the mechanical efficiency is lower than 50%. Okamura et al.<sup>10</sup> developed an algorithm to simultaneously display translational and cutting forces for a realistic cutting simulation. They considered two cutting models: real tissue data, and analytical model. Callaghan et al.<sup>11</sup> presented the design and development of a force measurement test apparatus, which would serve as a sensor characterization and evaluation platform. Although, in the past decade many distinguished works have been presented in force sensing, however, still many problem remain unexplored which need to be investigated before the idea of smart grasper can find its place in minimally invasive surgery. The works on giving sense of force to the surgeon are very scars and limited for remote tele-operation and robotic surgery. According to the best knowledge of the authors, sensing force for common grasper has not been well studied.



**Figure 1** Minimally invasive surgery.

## Governing equation for a smart grasper

Piezoelectricity is a coupling between a material's mechanical and electrical behaviors. When a piezoelectric material is squeezed, an electric charge collects on its surface (direct effect). Conversely, when a piezoelectric material is subjected to an electric field, it exhibits a mechanical deformation (converse effect). Applying an electric voltage to the electrodes of piezoelectric material will induce a mechanical deformation according to the magnitude and sign of applied voltage. Direct piezoelectric effect is the electric polarization produced in the dielectric as a result of applied stress. Indirect (or converse) piezoelectric effect is the strain obtained as a result of polarization by applied electric potential difference across the crystal. In both the effects, the stress/strain and the polarization are directly proportional to each other and change sign/direction with each other. The layer can also be used for actuation mechanism via converse effect. Since these active layers are of small thickness compared to the core material, we assume linear piezoelectric properties.

For direct coupling:

$$D = [e]\{\varepsilon\} - [p]\{E\} \quad (1)$$

And for converse coupling:

$$\sigma = [C]\{\varepsilon\} - [e]\{E\} \quad (2)$$

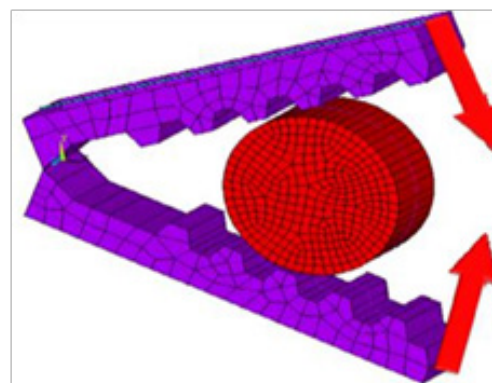
Where:  $\{\sigma\}$ ,  $\{\varepsilon\}$ ,  $\{D\}$ ,  $\{E\}$  are the stress, strain, electric displacement and electric field vectors, and  $[C]$ ,  $[e]$  and  $[p]$  are the elasticity, piezoelectric and dielectric constant matrices, respectively.

## Materials and method

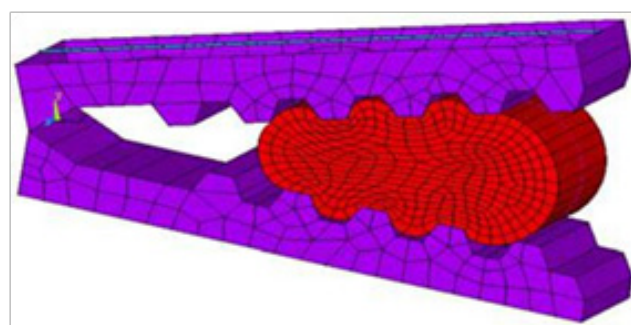
In this work first a prototype integrated with piezoelectric layer at the fixed point as shown in Figure 2. Construction of the material for the grasper was brass with a Young's modulus of elasticity of 100GPa and a Poisson ratio of 0.34. A layer of piezoelectric with dimensions of 22mm in length and 0.1mm in thickness was positioned on jaw surface and on this layer we attached 5 electrodes at 5 different locations. In this section modeling and analysis is performed for the time when grasper grip a subjects like rubber, foam and muscle with its tooth, this part is very similar to the real action of the grasper in surgery. In order to investigate the behavior of generated voltage and strain, it was decided to employ a two parameter Mooney–Rivlin for each material. The Mooney–Rivlin constants used are shown in Table 1. Mechanical model has 22mm in length and 3mm in width with tooth width; length of each tooth is 1 mm with 1 mm in width, the subject who is grasped assumes a hyper elastic material with 9.2mm in diameter (Figure 2). In reality when a force applied at grasper handle, force transmit through the link to the jaws and due to this force, jaws move respect to the magnitude of force and the subject with lied between two jaws. However at this circumstance study performs on the jaws which get motion in Y direction axis.

**Table 1** Hyper elastic Constant

Subject	C10 (MPa)	C01 (MPa)
Rubber	0.293	0.177
Foam	0.382	0.096
Muscle	0.03	0.01



**Figure 2** Grasper jaw with a substance between teeth.



**Figure 3** Grasper jaw after applied force.

## Modeling and analysis

To study the reaction of the tissue when grasper hold the organs or tissue and the generated strain along the top surface of the jaw and respectively generated the voltage, displacement applied at the tip of the grasper jaw. The boundary condition in this model is based on the real grasper jaw have revolution around the pivot point. With the jaws motion depend on the stiffness of the griped subject, reaction force will generated along the jaw. To analysis effect of jaw motion with applied displacement on tip point, 4mm displacement applied upper and lower jaw tip in negative and positive direction of Y axis respectively. Generated strain and stress in hyper elastic material when a subject as rubber squeezed by jaws are shown respectively in Figures 4 & 5. With respect to these figures we can determine strain and stress are at their high level where the subject squeezed more than other part and receive more deformation. Maximum strain and stress value generated on top surface of the jaw are  $5.35 \times 10^{-4}$  and 0.0021 respectively and occur at 13mm from pivot joint in x directional axis. As discussed before, there is relationship between strain and voltage in piezoelectric materials such as PVDF, so with considering this theory, high voltage reveal at the point which there is high strain. Figure 6 show electrodes which bounded between 10mm to 12mm and between 14.5 to 16.5mm have maximum value and it is due to generated higher strain then the other parts (Figure 7). This procedure performed again for subjects as foam and muscle with hyper elastic constant as defined in Table 1. Results of each materials compare with other one and all of them shown in one graph for better comparison. In Figure 8 generated strain along the sensor for each material is shown, with respect to this result, it is clear the position

where subject griped has the larger strain, and this strain is related to the stiffness of material. Also as discussed before strain and voltage on PVDF materials has a relationship, so with this strain we have a voltage on PVDF sensor which shown in Figure 9. For materials with high stiffness generated strain and respect to strain generated voltage is higher than the material with lower stiffness. Considering the softness of materials and applied displacement on each subject, a reaction force will generated at the jaw tip which this result for each material shown in Figure 10.

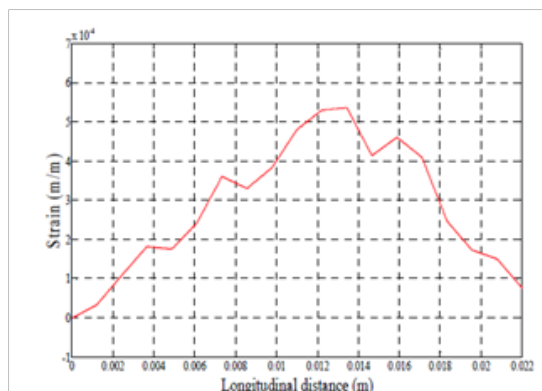


Figure 4 Generated strain along the PVDF sensor.

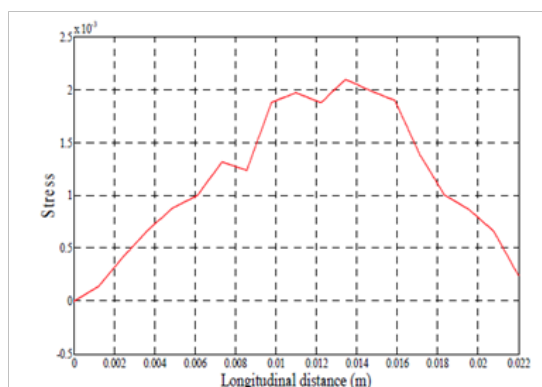


Figure 5 Generated stress along the PVDF sensor for a subject as rubber.

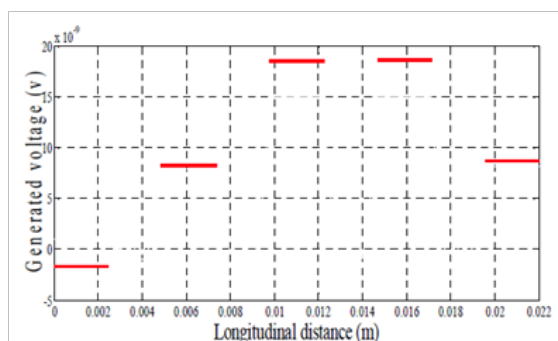


Figure 6 Generated voltages along the sensor for a subject as rubber.

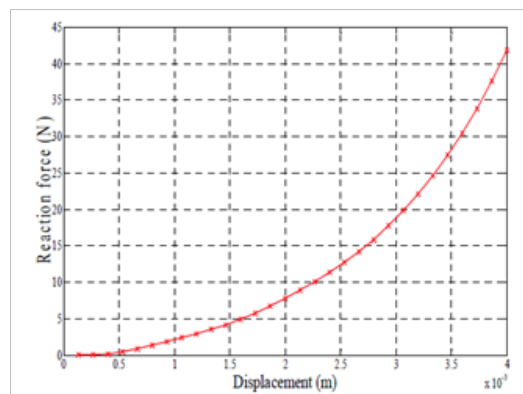


Figure 7 Relation between jaw displacement and reaction force.

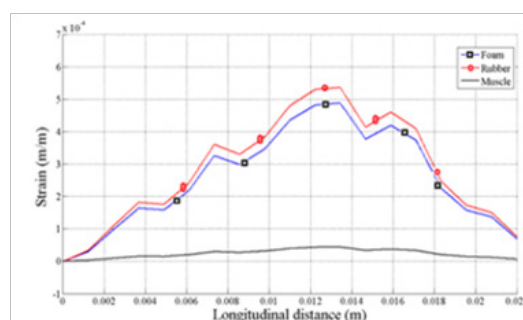


Figure 8 Generated strain by applies displacement for different subject.

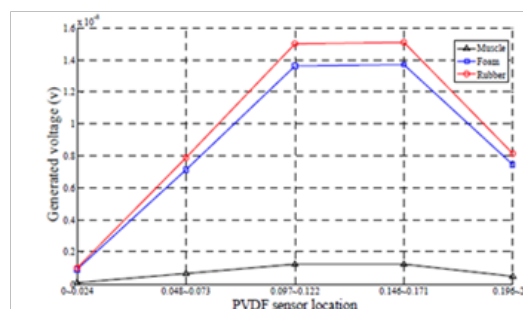


Figure 9 Generated voltages by applied displacement for different subject.

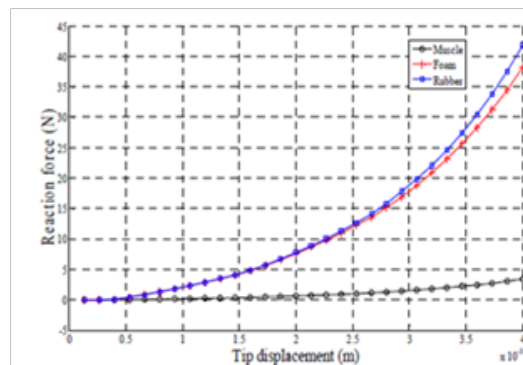


Figure 10 Reaction force by applied displacement for different subject.



## Conclusion and future work

The results of the present work would provide valuable guidelines in design and implementation of smart graspers in MIS. With respect to generated voltage along the PVDF sensor which patch on the grasper jaw it is possible to recognize the softness of the gripped object by grasper and further with a comparison this obtained result with a database which is experimentally generated for each organ and tissue, recognition the tissue and maximum force which surgeon can applied on this organ is possible. The use of these novel smart graspers would highly improve and facilitate the MIS by providing a complete feeling of touch and force to the surgeon and make a real-time alert which in turns, prevent possible damage to the tissue/organ due to excessive force applied by the surgeon. In addition, the smart graspers can potentially be used as educational tools, surgical simulators as well as in Tele-Robotic surgery. Utilizing Artificial Intelligence (AI) techniques such as Neural Networks<sup>12-19</sup>, Fuzzy logic<sup>20</sup>, Ring Probabilistic Logic Neuron<sup>21,22</sup> can be utilized to model the generated data by sensing the material in minimally invasive surgery, and to get the reliable data the AI models can be optimized using Genetic Algorithm<sup>23,24</sup>, Particle Swarm<sup>21</sup> and other AI optimization techniques.

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## Conflict of interest

The author declares there is no conflict of interest.

## References

- Dean J Callaghan, Mark M McGrath. A force measurement evaluation tool for tele robotic cutting applications: development of an effective characterization platform. *International Journal of Mathematical, Physical and Engineering Sciences*. 2007;1(3):1–7.
- Tavakoli M, Patel RV, Moallem M. A Force Reflective Master-Slave System for Minimally Invasive Surgery. Intl Conference on Intelligent Robots and Systems; Las Vegas, Nevada. IEEE; 2003.
- Sokhanvar S, Packirisamy M, Dargahi J. A multifunctional PVDF-based tactile sensor for minimally invasive surgery. *Smart Mater Struct*. 2007;16(4):989–998.
- Shikida M, Shimizu T, Sato K, et al. Active tactile sensor for detecting contact force and hardness of an object. *Sensors Actuators*. 2003;103(1–2):213–218.
- Dargahi J. A piezoelectric tactile sensor with three sensing elements for robotic, endoscopic, and prosthetic applications. *Sensors and Actuators*. 2000;80(1):23–30.
- Narayanan NB, Bonakdar A, Dargahi J, et al. Design and analysis of a micromachined piezoelectric sensor for measuring the viscoelastic properties of tissues in minimally invasive surgery. *Smart Mater Struct*. 2006;15(6):1684–1690.
- Rosen J, Hannaford B, Mac Farlane MP, et al. Force controlled and tele operated endoscopic grasper for minimally invasive surgery experimental performance evaluation. *IEEE Transactions on Biomedical Engineering*. 1999;46(10):1212–1221.
- Tholey G, Chanthasopeephan T, Hu T, et al. Measuring grasping and cutting forces for reality-based haptic modeling. *Int Congress and Series*. 2003;1256:794–800.
- Sjoerdsma W, Herder JL, Horward MJ, et al. Force transmission of laparoscopic grasping instruments. *Minimally Invasive Therapy & Allied Technologies*. 1997;6(4):74–278.
- Okamura AM, Webster RJ, Nolin JT, et al. The haptic scissors: Cutting in virtual environments. In *Proc IEEE Int Conf Robot Autom*. 2003. p. 828–833.
- Callaghan DJ, McGrath MM. A force measurement evaluation tool for tele robotic cutting applications: development of an effective characterization platform. *International Journal of Mathematical, Physical and Engineering Sciences*. 2008;1(3):144–150.
- Aydin Azizi, Farshid Entessari, Kambiz Ghaemi Osgouie, Amirhossein rezaei rashnoodi: introducing neural networks as a computational intelligent technique. *Intelligent Materials and Mechatronics*. 2014;464:369–374.
- Sajad Rashidnejhad, Amir Hossein Asfia, Kambiz Ghaemi Osgouie, et al. Optimal trajectory planning for parallel robots considering time-jerk. *Applied Mechanics and Materials*. 2013;390:471–477.
- Aydin Azizi, Farshid Entesari, Kambiz Ghaemi Osgouie, et al. Intelligent mobile robot navigation in an uncertain dynamic environment. *Mechanics, Simulation and Control*. 2013;367:388–392.
- Aydin Azizi, Navid Seifipour. Modeling of dermal wound healing-remodeling phase by neural networks. *Computer Science and Information Technology - Spring Conference*; 2009.
- Aydin Azizi, Navid Seifipour. Mathematical modeling of dermal wound healing's remodeling phase. a finite element solution. *Computer Science and Information Technology - Spring Conference*; 2009.
- Aydin Azizi, Kambiz Ghaemi Osgouie. Modeling of forced dermal wound healing using intelligent techniques. *Computer and Automation Engineering (ICCAE), The 2<sup>nd</sup> International Conference*; 2010 Feb 26–28; Singapore. IEEE; 2010.
- Aydin Azizi, Kambiz Ghaemi Osgouie. Mathematical modeling of dermal wound healing: A numerical solution. *Computer and Automation Engineering (ICCAE), The 2<sup>nd</sup> International Conference*; 2010 Feb 26–28; Singapore. IEEE; 2010.
- Aydin Azizi, Kambiz Ghaemi Osgouie. Dermal wound healing-remodeling phase: A biological review. *Computer and Automation Engineering (ICCAE), The 2<sup>nd</sup> International Conference*; 2010 Feb 26–28; Singapore. IEEE; 2010.
- Aydin Azizi, Kambiz Ghaemi Osgouie, Sajad Rashidnejhad, Mostafa Cheragh, et al. Modeling of melatonin behavior in major depression. *A Fuzzy Logic Modeling*. 2013;367:317–321.
- Azizi A, Barenji AV, Barenji RV, et al. Optimizing RFID network planning through ring probabilistic logic neurons. *Advances in Mechanical Engineering*. 2016;8(8):1–12.
- Azizi A, Barenji AV, Barenji RV, et al. Modeling mechanical properties of FSW thick pure copper plates and optimizing it utilizing artificial intelligence techniques. *International Journal of Sensor Networks and Data Communications*. 2016;5(2).
- Ashkzari A, Azizi A. Introducing genetic algorithm as an intelligent optimization technique. *Applied Mechanics and Materials*. 2014;568:793–797.
- Kambiz Ghaemi Osgouie, Aydin Azizi. Optimizing fuzzy logic controller for diabetes type I by genetic algorithm. *Computer and Automation Engineering (ICCAE), The 2<sup>nd</sup> International Conference*; 2010 Feb 26–28; Singapore. IEEE; 2010.