Development of flexible array tactile sensors

Drimus, Alin; Marian, Nicolae; Bilberg, Arne

Paper Data	DPN	First Name(s)	Family Name	Mentor
Author 1:	24238	Alin Marian	Drimus	No
Author 2:	24259	Nicolae	Marian	No
Author 3:	19696	Arne	Bilberg	No
Author 4:		Klicken Sie hier, um Text einzugeben.	Klicken Sie hier, um Text einzugeben.	No
Author 5:		Klicken Sie hier, um Text einzugeben.	Klicken Sie hier, um Text einzugeben.	No
Author 6:		Klicken Sie hier, um Text einzugeben.	Klicken Sie hier, um Text einzugeben.	No

Corresponding Author:	Author 1	E-Mail:	drimus@mci.sdu.dk

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Abstract: *In this paper we describe the development of an array tactile sensor for use in robotic grippers based on a flexible piezoresistive material. We start by comparing different cell structures in terms of output characteristics and we construct an array of cells in a row and columns layout. A real time data acquisition system scans all the cells and converts electrical resistance to tactile pressure maps. We validate that this information can be used to improve grasping and perform object recognition.*

Key words: *piezoresistivity, tactile, sensor, pressure, robotics*

1. INTRODUCTION

For handling unkown objects in unstructured environments, tactile sensing can prove to be valuable by providing information complementary to vision. By using the sense of touch, humans can perceive mechanical properties of the objects they are manipulating, such as compliance, friction, texture or mass. Force and tactile sensing at the finger-object contact are essential for fine manipulation and complex tasks with changing grasp requirements (Howe, 94).

The two most important components of tactile interaction are the dynamic sensing, where we deal with responses caused by changes in the condition of contacts, based on movements of the fingers, vibrations or slip occurance and static sensing, where the distribution of tactile mechanoreceptors is used to determine local surface shape and pressure distribution. There are a few technologies that can be used for manufacturing tactile array sensors and the most used are piezoresistive (rubbers or inks), piezocapacitive, piezoelectrical and optical (Cutkosky et al., 2008). Our work will consider the static tactile arrays based on piezoresistive technology.

Even though more than 30 years of research into development of tactile sensors have passed, there has only been little progress achieved compared to vision. The biggest problems concern the difficulty of wiring and fragility of such sensors, not to mention the cost and difficulty of customization (Cutkosky et al., 2008). The requirements for a tactile sensor array similar to an artificial skin would be:

- conformability and thin, to suit any kind of finger or gripper
- spatial sensing resolution and sensitivity similar to the human skin
- robustness and repeatability for industrial use
- low cost for development and easy to replace

In the last decades, quite a few sensor prototypes have been developed. Flexible sensors based on pressure conductive rubber with 3x16 cells were developed using a stitched electrode structure, but the construction method and the leak currents bring high variations in the measurements (Shimojo et al., 2004). Industrial tactile sensors have been developed by Weiss (Weiß & Wörn, 2005) but they are not flexible and have low resolution, 6x14 cells in 2.4cm x 5cm. A flexible 16x16 sensor array with 1 mm spatial resolution was developed for minimal invasive surgery, but the sensor fails to give steady output for static stimuli, and has a high hysteresis and non-linearity (Goethals et al., 2008). A combination of static and dynamic sensor was developed to address both pressure profiles and slippage, but the design has only 4x7 cells, and a number of wires equal to the number of cells (Göger et al., 2009).

2. DEVELOPMENT OF A TACTILE SENSING ARRAY

2.1 CSA rubber

CSA material is a piezoresistive rubber that changes its electrical resistance locally in relation with an induced strain caused by application of pressure. When no external force is applied, the electric conductive particles do not touch each other, therefore the material shows a high resistance (in the order of hundreds of kilo ohms). But, if external force is applied the distance between particles is reduced, there are more contact points between particles. The contact resistance between particles drops and electrical current will be allowed to flow through. In this case, the resistance will drop considerably (to the range of hundreds of ohms).

2.2 Constructing a tactile cell

In order to study the behaviour of the piezoresistive rubber as the base of a tactile array sensor we start by investigating the properties of a single cell, with different electrode structures. Besides from the electrical resistance properties of the piezoresistive rubber, there are also other aspects to take into consideration: area of the electrodes and contact resistance. We have investigated different types of electrodes with 1mm spacing: copper stripes, stitched wires, tin wires, conductive polymer with silver with different subtrates (paper, tape) and the influence of contact type (permanent or floating) between the electrodes and the conductive rubber. We have also investigated the sensitivity of two types of structures: a single sided approach and a double sided approach, where the piezoresistive rubber is sandwiched between the two electrodes. The results showed highest sensitivity and dynamic range for the double sided approach, as the resistance of the piezoresistive rubber varies mostly in the thickness plane. In terms of threshold sensitivity, the best results were obtained by using a floating electrical contact, because the contact resistance has a major influence on the overall measured resistance and even if highly non-linear, it varies mostly at gentle contact. We managed to get to a sensitivity threshold of about 50 grams force. The most repeatable and stable output was given by a flexible substrate (rubber tape) with painted conductive polymer electrodes. The change of resistance in relation with a force applied using an actuator is displayed in Fig. 1. We can observe that there is a non-linear behaviour for maximum force applied and also that the change in resistance is very sudden once a specific threshold is passed. Even though hysteresis, relaxation and other non-linearities are present - this is one of the disadvantages of piezoresistive materials, the output shows that non-absolute measurements of force can be done.

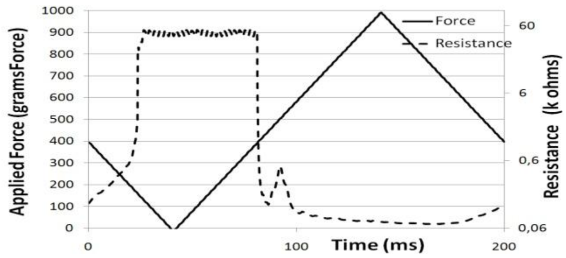

Fig.1. Tactile cell response for 0-1000g Force

2.3 Constructing a tactile array sensor

A very common solution used to address the complexity of wiring is the use of rows and columns of electrodes. This technique implies equally spaced rows of electrodes on the face of the material, followed by a perpendicular arrangement of equally spaced columns on the back of the material. This structure decreases the number of wires to a minimum compared to a normal array of sensors, from $2 \times n^2$ to $2 \times n$ wires. The tactile array sensor prototype is 2 cm x 2 cm, where each cell is 1.6 mm x 1.6 mm and is close to the size of the mechanoreceptors in the human skin. Fig. 2 represents a 4x4 array.

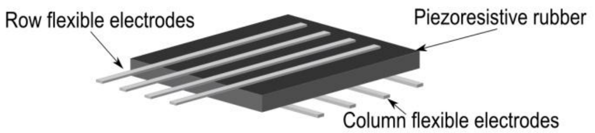

Fig. 2. Tactile sensing array for 4 rows and 4 columns

2.4 Data acquisition

Data acquisition is realised by applying a voltage on each of the rows and scanning the columns one by one, iteratively, in order to extract the electrical resistance at the overlapping of the selected row and column. A voltage divider technique translates the applied pressure over the specific cell into voltage, which is adaptively converted to 12 bit for small pressure and 7 bit for larger pressure, overall 256 different pressure levels. An 8 bit value allows a reasonable discrimination between pressure levels and increases communication speed. In order to address 100 tactile cells we use a dsPIC33f with 10 ports used for ADC conversion and 10 ports used for selecting the supply lines. The data is sent serially to a PC with a minimum of 50 fps. Because of the small distance between the electrodes, properties of the rubber and of the multiplexing algorithm, there may appear leak currents or phantom cells (Shimojo et al., 2004, Goethals et al., 2008). In order to address this issue, all the rows that are not active are connected to the ground. Due to imperfections in manufacturing and non-ideal contact between the piezoresistive material and the electrodes, there are different responses from neighbouring cells for the same stimuli (up to 5% of the whole range). A solution for this is to apply an even pressure over all cells and to record each cells maximum. For each cell, the range between the minimum and the maximum is normalized (0 - 255) and this value is sent further.

2.5 Use of tactile information

Information given by the sensor is converted into a 10x10 pressure map and can be used as the input to a grasp controller that can try to maximize the touched area and ensure the optimal force applied to the object. Another area where pressure maps prove helpful is recognition of different objects by unique contact profiles (Göger et al., 2009,) or recognition of objects based on tactile pressure maps from multiple grasps (Schneider et al., 2009). Preliminary tests show that such a sensor prototype can provide information regarding geometrical features of small grasped objects. For this we have used the sensor and pressed against various small sized objects like plastic rings, plastic circles washers and tip of screwdriver. The results are displayed in Fig.3. It is possible to discriminate between different objects based on their contact geometrical features and size easier than with a vision system, due to removing of scaling and coloring.

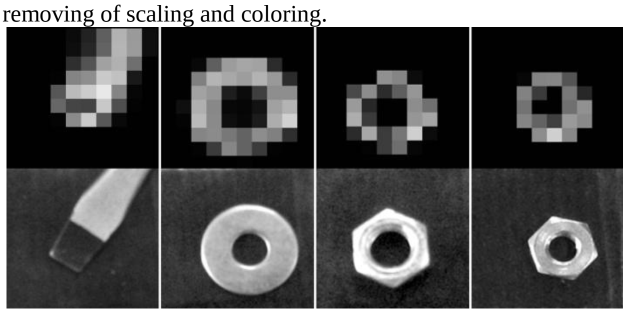
Fig.3. Tactile images (up) for different small objects (down)

3. CONCLUSION

In this article we describe the development of tactile array sensors using piezoresistive rubber. We start from constructing a tactile cell, investigate its properties and continue with an array of cells that fullfills our set of requirements. We describe the data acquisition system and we show the potential use of tactile information in object identification and reactive grasping. Even though hysteresis, relaxation, wiring complexity, sensitivity and robustness are current issues to address, we suggest that such an array sensor device can be successfully used in robotic grippers or anthropomorphous hands for building fingertips and palm tactile sensors. Future work will address using this sensor for adaptive grasping and recognizing objects based on their geometrical features.

4. ACKNOWLEDGEMENTS

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