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Research of Tactile Structure Based on MEMS Sensitive Elements for Robotics and Tactile Diagnostics Devices

D.V. Gusev, R.S. Litvinenko and V.S. Sukhanov
SPC "Technological Center", Georgievskiy Proezd, 5 Bld., Zelenograd, Moscow, Russia

Abstract: Tactile sensor technologies are rapidly being evolved and interest in them is growing steadily. The main constraint in this area is not the limitation on the processing power of the applied processors but the absence of technology capable of transforming the volumetric tactile interaction into an electrical signal. The study presents, the design of a complex tactile structure based on silicon MEMS-CMOS crystals, containing piezoresistive sensitive elements. The tactile structure is developed for use in robotics and tactile diagnostics applications. The structure is covered with silicon layer for protection of the sensitive elements. The study presents, the results of research of determining the location of point-touch.

Key words: Minimally Invasive Surgery (MIS), MEMS, robotics, tactile sensor, trausborming, transforming

INTRODUCTION

Despite, the fact that the tactile interaction is one of the key interactions between a robot, the environme and man in the world practice of robotics bionic arms having the tactile sensitivity are just beginning to appear. In addition in the area of human limb prosthetics, such studies are only beginning to be carried out abroad. Manufacturers of artificial limbs for humans offer mainly the sensorless model in the market. Devices with tactile sensitivity are currently in the development phase and have entry level indicators. Thus, the project's theme corresponds to the latest achievements of world practice.

In medicine a trend is observed for incorporation of MEMS devices in surgical tools. MEMS technologies allow surgeons to obtain information on the density and temperature of an investigated tissue in a real time mode. Besides, MEMS technologies ensure more effective and fast methods for capture, cutting and extraction of tissues, improving the results of the surgical treatment (Rebello, 2004).

In open operations a surgeon gets an access to the organs and tissues and can manipulate them freely. However, in many cases a cut, providing the access to the required area, can injure a patient more than the operation itself.

Methods of Minimally Invasive Surgery (MIS) are now rapidly developing because they allow a surgeon not to come into direct contact with the internal organs of a patient (Preusche *et al*., 2002). The importance of MIS can hardly be overestimated because operations do not require big cuts, the loss of blood and risk of infection are lower, rehabilitation period is shorter and cosmetic results are better.

A surgeon receives information concerning the condition of an investigated tissue mainly by means of touch. In this connection in order to advance MIS it necessary to develop tools which allow obtaining tactile information.

MATERIALS AND METHODS

Theoretical part: Silicon piezoresistive pressure transducers are the most suitable for creating tactile sensors. This statement is reinforced by the global experience (Dahiya and Valle, 2013) which shows that the process of creating arrays with a high density of sensing elements is joined with silicon technology, including MEMS devices. One of the key benefits of silicon MEMS devices is the ability to create sensitive elements on production lines for CMOS circuits. Silicon bulk micromachining technology is well studied and allows to produce crystals with high (>40 units cm^{-2}) density of sensitive elements. Silicon also has a strong piezoresistive effect, almost ideal elastic characteristic, high mechanical strength and stable electrical characteristics for a long time.

Due to the high linearity of response and low hysteresis value high accuracy of the output signal of the transducer can be achieved. At the same time, the problem of temperature dependence can be solved by means of temperature compensation.

Corresponding Author: D.V. Gusev, SPC "Technological Center", Georgievskiy Proezd, 5 Bld., Zelenograd, Moscow, Russia

For the effective application of sensor matrixes in haptic diagnostics devices it is required to cover with sensors a surface space comparable to the phalanx of the surgeons finger. This means that the design of the matrix should allow to combine multiple chips into a single device. In such cases, the problem of a huge number of interconnects arises which not only affects the overall reliability of the product but also creates obstacles to miniaturization. The only solution is the integration of active devices directly into the crystal.

RESULTS AND DISCUSSION

Experimental part: Based on many years of experience (Amelichev *et al*., 2012) in the field of tactile transducers in SPC "Technological Center" crystal MIPD-32 (Fig. 1) was developed. Crystal, made by silicon bulk micromachining technology, is a matrix of 32 pressure sensitive elements with a membrane thickness of 17±3 μm. Sensitive elements of the matrix use tensoelectrical effect occurring in silicon under the action of external mechanical impact and are designed for use in the pressure range 0/100 kPa. The pressure is applied on the lower side of the crystal. The size of the crystal is 6.85×6.85 mm. Besides 32 tensobridges the crystal contains a temperature sensor for temperature compensation. Each sensitive element is sequentially queried using the 34 bit shift register scheme on static synchronous D-flip-flops, clocked by the signal level and CMOS pass keys. Pass keys and shift register are integrated directly into the MIPD-32 which means combining MEMS and CMOS technologies on a single chip.

Crystals are designed to be set in modules and then in turn modules are combined together to form a complex structure (cluster). The form of the cluster can be different, also it can cover not flat surfaces. Cluster scheme is shown in Fig. 1.

The cluster can be covered with silicone layer to protect the sensitive elements. In the research, a 0.4 mm diameter needle was used to point-touch the cluster in a straight line passing through the centers of the membranes of one of the crystals. Every touch was made with a pitch of 80 μm from the previous one. The experiment was performed at different thicknesses of the protective cover: 0-500 μm. Processed data for clusters with different thicknesses of the protective cover is shown on Fig. 2.

Figure 2 shows the presence of insensitivity zones between the channels of the crystal. This means that the protective cover does not bring the ambiguity in determining the point-touch location. The simultaneous spatial threshold tactile sensitivity in the fingertips with a simultaneous touch at two points is of the order of 1-3 mm with a series is about 0.7 mm. In the developed cluster distance between the pressure sensitive channels is 1.08 mm. Thus, the ability to determine the point-touch location approaches the human senses.

Figure 3 shows the comparative characteristics of zero drift in the scale corresponding to full output signals scale of the ADC. In the absence of the cover, the zero drift is small and can be neglected. With the increasing thickness of the protective cover temperature drift increases significantly but in this case, does not exit out of the limits.

During the operation of the cluster it is necessary to take measures to suppress this drift. This can be done programmatically, performing temperature calibration of the cluster. The input parameter of this calibration is the temperature which can be read from the digital data received from the cluster (crystal has an integrated temperature sensor). The research showed that the operating temperature range is -40 to +85°C (standard industrial temperature range).

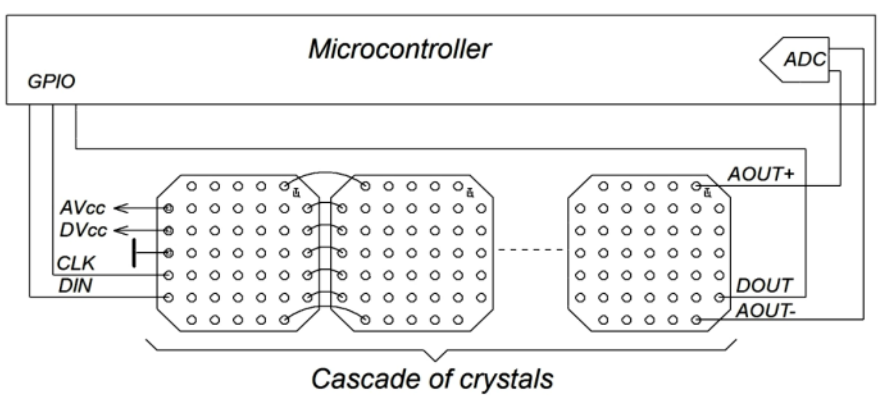

Fig. 1: Cluster scheme

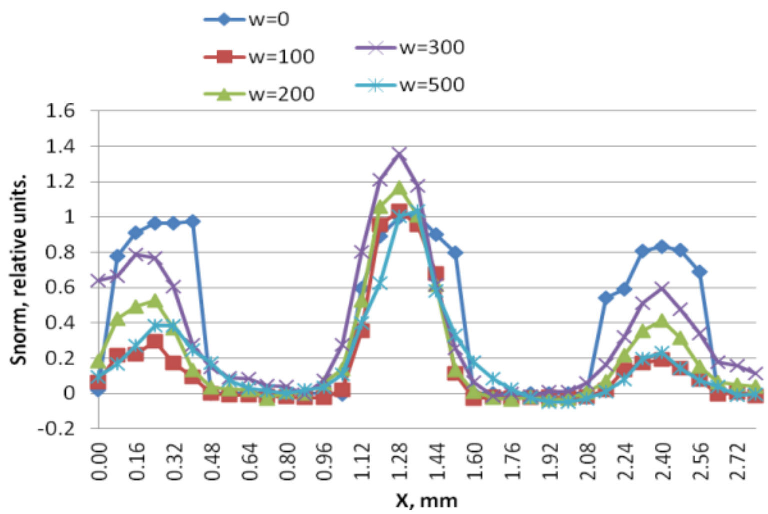

Fig. 2: Dependence of normalized sensitivity from the point-touch location

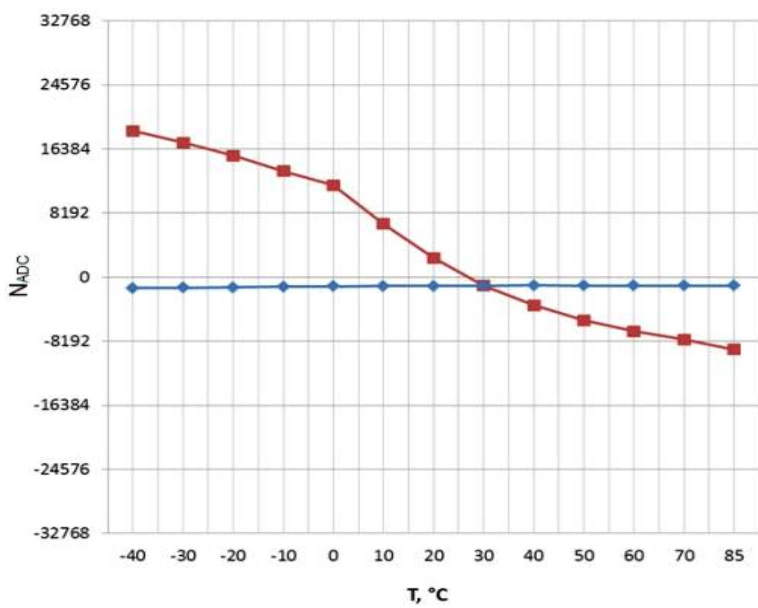

Fig. 3: Zero drift for cluster with protective cover and without it

CONCLUSION

The developed cluster can be used in robotics haptic diagnostic devices as a sensor for obtaining tactile information. It is possible, to combine modules in a complex structure to embrace large areas with tactile sensors. Cluster can be protected with silicon cover of different thickness. The presence of insensitivity zones between the channels does not bring the ambiguity in determining the point-touch location. Zero drift problem can be solved by temperature compensation means.

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