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Tactile sensors and their use in industrial, robotic and medical applications

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Abstract

This article is about a special type of pressure sensors usually labelled tactile sensors. After a short overview on the subject, two application examples, one in the medical domain developed by the authors for heart rate variability using an electrets-based pressure sensor, are presented.

Keywords: pressure sensing, tactile sensors, artificial skins, haptic sensing

1. Introduction

In many practical situations, it is of paramount importance to have the information of pressure distribution on a defined surface. Industry, particular the one associated to car assembly, is a source of applications that do benefit from such pressure measurements. Some examples: car door mounting, brakes and friction plates manufacturing, automotive seat design, bead seat /seal pressure profile of car tire to wheel interface, catalytic converter canning, fuel cell design, analysis of engine assembly process and gasket design, analysis of hose crimp pressures during manufacture and assembly, pinch roller machine set-up and alignment, machine set-up and design, and analysis of glass polishing. Another important domain recommending surface pressure distribution measurement is robotics. The incorporation of adequate pressure sensors on a robot handling and grasping end effectors and of software can convey haptic capabilities to a robot. Providing touch to a robot allows it to manipulate delicate objects and to assess their shape, hardness and texture. Some of such robots are used in medical surgery and their haptic capabilities can be used both to transmit the surgeon information of the instrument-patient interface and to “feel” organs and tissues, thus replacing the human sense of touch.

The pressure sensors required for the type of applications just mentioned have special requirements. One of them has to do with size. Generally speaking, the surface where sensing means are to be installed is small, ranging from 1 m^2 to 1 mm^2 or even less. On the other hand, the number of sensing points (each usually called tactel, taxtel, taxel or sensel in analogy to a pixel (picture element) in an image sensing array) in such a small area is high, say from tens to tens of thousand. These characteristics alone point to the need to implement such pressure sensors as arrays of sensors manufactured using special techniques. Because the main use of these arrays of pressure sensors is for tactile and touch sensing they are usually known as tactile sensors or artificial skins.

In what concerns the transduction principle used to implement the taxel, the number of solutions is high. In tactile sensing, we are in the domain of force (or pressure) measurement and so most of those solutions are common to normal force transduction.

In the following paragraphs, and after a short reference to tactile sensor implementation, two applications are presented. One of them concerns the medical domain and was developed by the authors for heart rate variability assessment. The paper ends with a conclusion section where the authors make some considerations on the present and future of tactile sensing.

2. Tactile sensors' implementation

In spite of the variety of technical solutions currently used to implement tactile sensors, we mention here just those that are more common or, according to us, more promising. Further information on tactile sensors, namely on its implementation, can be found in the literature, e.g. in [1-3].

i. Resistive based sensors. The basic principle of this type of sensor is the change of electrical resistance with pressure of a material placed between two electrodes or in touch with two electrodes placed at one side of the material [4]. One solution to implement this pressure sensitive resistor is using a conductive elastomer or foam or elastomer cords laid in a grid pattern, with the resistance measurements being taken at the points of intersection. Resistive taxels can also be made using conductive polymers and thin semi-conductive coating (ink). In the first case, the polymer is made piezoresistive by screen printing it with a film of conductive and non-conductive micron particles.

ii. The conditioning circuits of resistive-based tactile sensors are fairly simple, which is one of their advantages. Figure 1 shows a 3x3 array of resistive taxels and the circuitry that can be used to implement a tactile transducer.

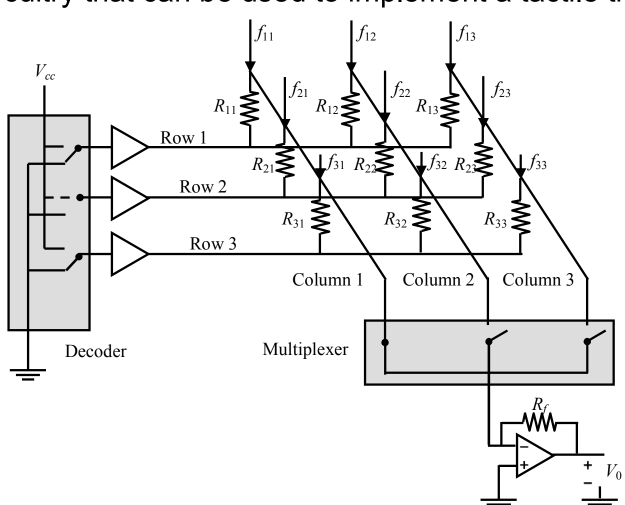
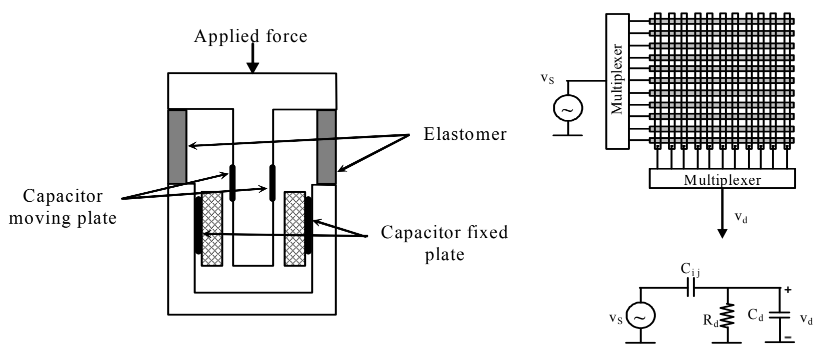


Fig. 1 – Resistive tactile transducer

iii. Capacitive based sensors. A capacitive taxel is a capacitor whose capacitance changes with the applied force. The force can produce either the change in the distance between capacitor plates or its area. Generally speaking, if the capacitor plates area to distance ratio is smaller than 1, the change of plates area is better, which recommends a coaxial cylindrical capacitor (Fig. 2 (a)). Nevertheless, parallel plate capacitors are easier to fabricate than cylindrical ones, which justify their popularity even nowadays (e.g. [5]). To measure the change in capacitance, several conditioning circuits can be used depending also on the type of the desired output signal. The circuit of Fig. 2 (b) yields an ac voltage, v_d whose value depends on the capacitance of each taxel, C_{ij}.



(a) (b)

Fig. 2 – (a) Capacitive taxel based on a cylindrical capacitor; (b) voltage-based conditioning circuit and its equivalent electric circuit: C_{ij} – taxel (i,j) capacitance; R_d and C_d – equivalent resistance and capacitance of the circuit yielding v_d

iv. Optical Sensors. The operating principles of optical-based sensors include modulation by the applied force of the transmitted light intensity, phase, or polarization and interaction of the applied force with the light external to the primary light path. Figure 3 shows obstruction-type optical taxels.

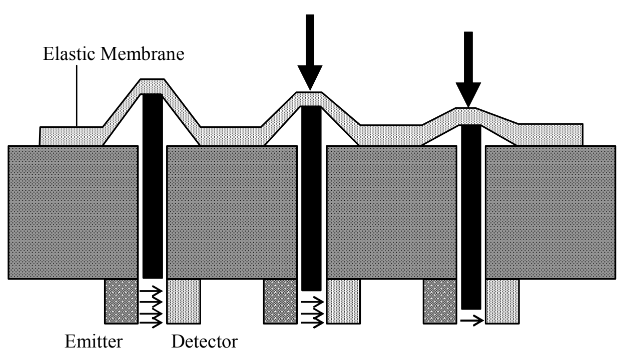


Fig. 3 – Optical obstruction-type taxels

Micro and nano-technologies are particularly attractive to tactile sensing implementation because they can produce not only high density arrays of sensors but also devices incorporating both the sensors, the required conditioning electronic circuits and even the hardware for signal acquisition, digital signal processing and transmission.

The large majority of tactile sensors recently developed use, more or less intensively, MEMS technology. They are either polymer with organic material substrate based or silicon based sensors.

Although to our knowledge no fully nanoscience based tactile sensor has yet been produced, there are however reports of tactile sensors using nano-materials (nano-particles and nano-wires) (e.g. [6]), some of them patented protected [7], and of nanomaterials that can be used for very low force sensing [8]. The tactile sensor reported in [9] is surely one of the most interesting and promising implementation using nano technologies.

3. Application examples

Pressure sensors such as tactile sensors are particularly useful in industrial, robotic, and medical applications. Two examples follow.

3.1 Braking systems

The analysis of the interface between a brake pad and rotor or brake shoe and drum is important for the design of car, train and aircraft braking systems. The analysis can be made by obtaining the dynamic forces and pressures at the interface. Figure 4 shows a solution for proposed by Tekscan [10] based on specially designed tactile sensors and software. There are two sensors with metric dimensions as the one depicted in the figure. Their characteristics are: overall dimensions: (1) L=373.9 mm, W=91.6 mm, A=190.1 mm; (2) L=398.6 mm, W=107.8 mm, A=190.1 mm; sensing region: (1) MW=110.0 mm, MH=44.9 mm, CW=1.5 mm, CS=2.5 mm, RW=0.8 mm, RS=2.0 mm; (2) MW=132.0 mm, MH=59.0 mm, CW=1.8 mm, CS=3.0 mm, RW=1.0 mm, RS=2.3 mm; total number of tactels (sensels): (1) 863, (2) 928; resolution: (1) 16.8 tactels per square centimeter; (2) 12.3 tactels per square centimeter. The bottom part of Fig. 4 shows how pressure data are output by the software. It is a colored image from blue to red (blue for the lowest and red for the highest pressure values) that allows an immediate and easy interpretation of the monitored interface.

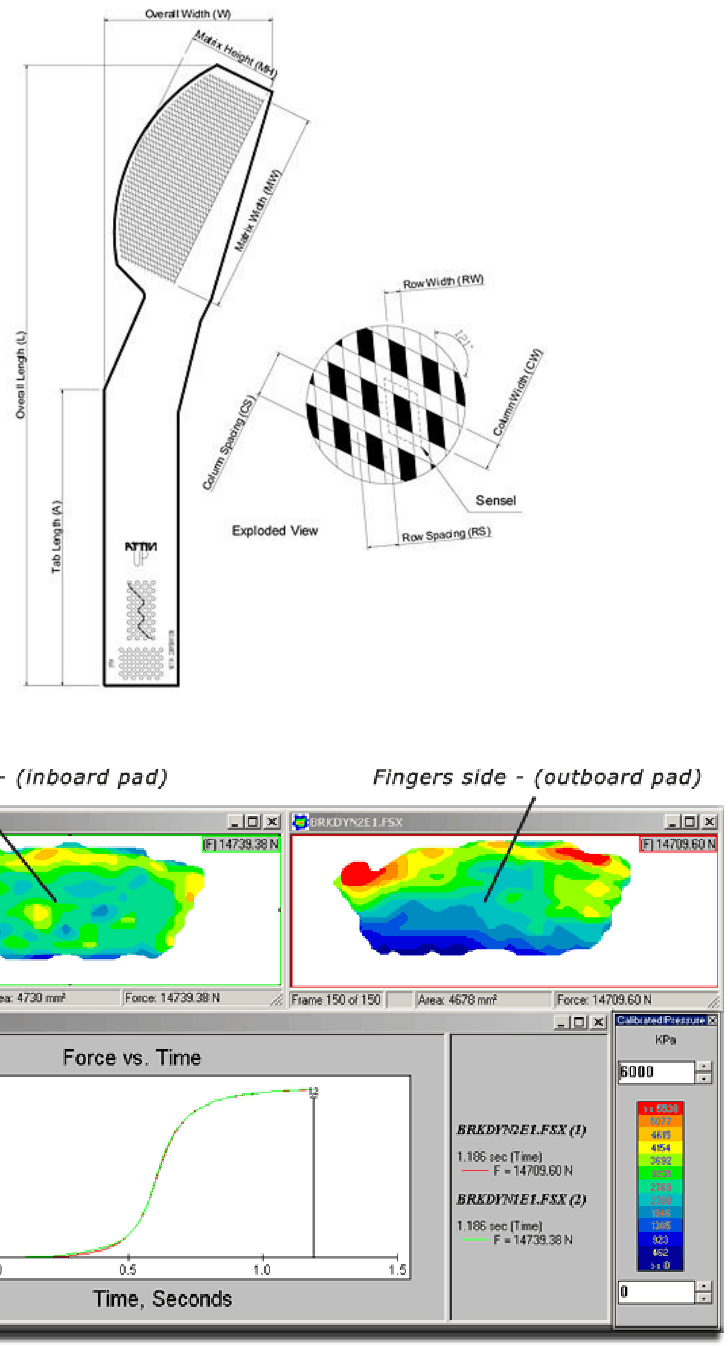


Fig. 4 – Braking system analysis. Top: sensor; bottom: difference in pressure pattern of inboard (piston side) and outboard (finger side) of brake pad

3.2 Ballistography

Ballistography is a method by which body vibrations caused by heart activity are registered. In our case, the purpose is to access the heart rate variability and the sensor used, although not classifiable as a tactile one, reacts to pressure.

An electrets film sensor (BCG-S) mounted on the backrest of a chair is used to measure the ballistocardiogram for a patient in a seated position (Fig.5). Skin conductance variation (SCV) is measured using a sensor (with two conductive discs) mounted on the arm of the same chair in order to evaluate aversive motivational functions, controlling passive avoidance and extinction – BIS. Conditioning circuits (CC) were designed and implemented to obtain time variable voltage signals applied to the analog inputs (AI0, AI1) of a low-cost multifunction board (NI USB-6008) connected to a laptop PC. They include an amplification scheme (charge amplifier for the BCG channel and voltage amplifier for the SCV channel). Some characteristics of the used board are: 12-bit resolution, up to 10kS/s acquisition rate, ±5V analogue input range. In the present case, the acquisition rate for the BCG and SCV channels is 1 kHz. Referring to the PGA1 and PGA2 programmable gain amplifiers control, four digital lines (PO0-PO3) of the NI USB-6008 digital port are used. Using switching schemes based on DG303, the current gain is modified to match the NI USB-6008 analogue input voltage range.

Figure 5 includes not only a block diagram of the hardware involved but also the time waveforms of the ballistocardiogram and of the skin conductance obtained from a subject under test.

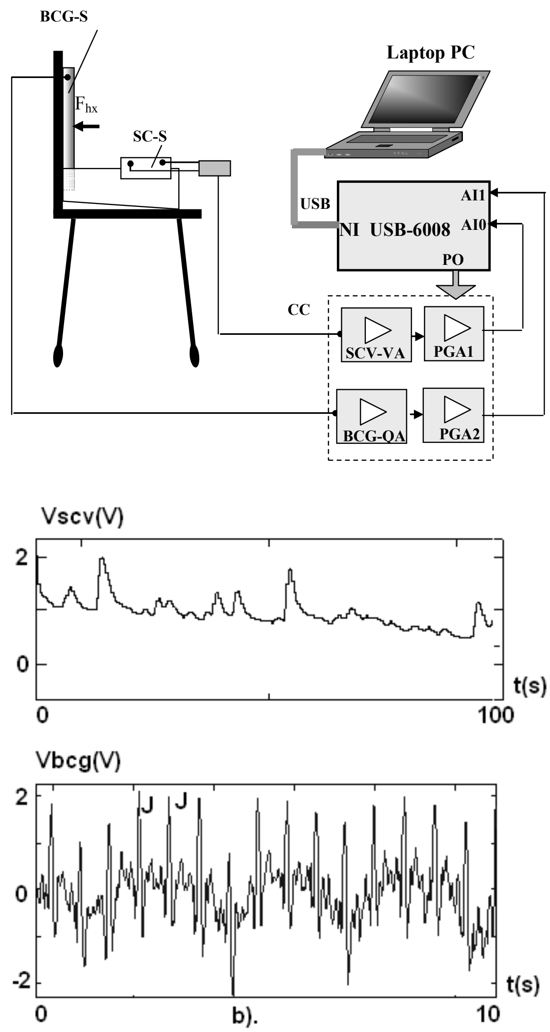


Fig. 5 - Top BCG and SCV measuring system block diagram (SC-S – skin conductivity sensor, BCG-S- ballistocardiogram sensor, CC-conditioning circuit, BCG-QA – ballistocardiogram charge amplifier, SCV-VA-skin conductivity variation voltage amplifier, PGA1, PGA2 – programmable gain amplifier; bottom: Vscv and Vbcg voltage waveforms

4. Conclusion

Tactile sensing is served by several transduction principles and micro and nanotechnologies provide the means to implement increasingly complex sensors.

The number of people involved in research and development of tactile and haptic sensing and the number of reported works has increased particularly in the last couple of years, but the use of tactile sensors is still extremely low and fails to show momentum. Why? We think that basically there is no real market-oriented driving force boosting the tactile sensing domain: industrial automation aims efficiency at low cost. This generally means usage of well established reliable and as simple as possible technologies. Robots with tactile sensing are not at that stage and some applications that could profit from them are implemented by forcing a structured environment and using simpler sensing devices like proximity sensors; other domains like medicine, particularly surgery, and service robotics have not been able to play that role until now. To this we must add two other considerations: (1) tactile and particularly haptic sensing is quite demanding not only in terms of hardware but also of software. The extraction of information from tactile sensors may require the implementation of complicated algorithms; (2) the hardware and software available, even at an experimental level, are still not adequate for some already defined needs.

Our vision of the future in what tactile sensing is concerned is optimistic but only moderately. Assuming that the industry will not change very much its production style in the near future, we think that it will be up to scientists and engineers to go on developing new sensors suitable for other domains of applications.

We expect and believe that the technology will be able to overcome some of the current limitations of tactile sensing such as taxel dimension (resolution) and arrangement (array organized sensors suffer from crosstalk, i.e. several taxels can be excited by a very localized force), and integration of all components required to output tactile sensation (sensors, conditioning circuits, processing units, etc.). Nanosciences and nanotechnologies will probably provide answers to these problems but no one can assure if the solutions will have a major impact on tactile sensor usage.

A final word about tactile sensing systems' calibration. Some sensor manufacturers do provide devices for calibration purposes. They are usually compressed-air or vacuum based systems whose aim is to apply the same pressure to all tactels. They are not generally purpose calibrating systems since they are designed having in mind the sensors produced by the manufacturer. The pressure at the tactels has an uncertainty no better than 1-3% of the target value. In conclusion, the calibration of multi-tactel tactile sensors is in general not satisfactorily possible and, in our opinion, remains a problem to be better solved in the future.

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