# Current trends in research and development of tensoresistive sensors

LEILA ZEVRI[a,*], IULIAN IORDACHE[a,b]

[a]*Valahia University from Târgovişte, Bd. Carol I, Nr. 2, 130024, Târgovişte, Dâmboviţa, Romania*
[b]*National Institute for Research in Electrical Engineering (INCDIE ICPE-CA), Splaiul Unirii, No. 313, Sector 3, 030138, Bucharest, Romania*

Pressure and strain measurements, evaluation of the mechanical load conditions are a special chapter of the materials science and engineering and the distinctive domain of sensors. This paper focuses on some of the current trends on research and development of the piezoresistive/tensoresistive sensors. Tensoresistive sensors are gaining renewed interest as the level of sophistication in the application of minimum invasive surgery and humanoid robots increases. The new application domains require versatile, autonomous, intelligent robots. Touch detection information can be used to determine if the robot is in contact with an object, which is the contact configuration, grasping, as well as stability and feedback, to control the robot force. MEMS tactile sensors include piezo-resistive, capacitive, piezoelectric and optical types. Because they are easy to manufacture and they have a low production cost the piezo-resistive sensors are widely used. Due to difficulties of applications of tactile sensors on a rigid body, recent reports have focused on MEMS tactile sensors based on polymers. Conducting polymers has excellent electrical, chemical and mechanical properties and they are useful for designing efficient, versatile and real-time response for different sensor applications. A frequent choice of pressure sensitive materials is elastomers that are enriched with conductive filler particles.

## 1. Introduction

Pressure sensors are expected to show good market growth as they are widely used across different application segments. The market is dominated by piezoresistive and capacitive sensors. Piezoresistive/tensoresistive sensors are used in automotive segments and medical applications, robotics, for a variety of applications such as petrochemicals, consumer electronics, utilities, and industrial segment while capacitive sensing is highly recommended in the process and petrochemical and oil and gas industries [1].

Piezoresistive sensors are among the first Micro-Electro-Mechanical-Systems (MEMS) devices and comprise a substantial market share of MEMS sensors in the market today [2]. MEMS tactile sensors offer several advantages compared with conventional sensors, such as miniaturization, high sensitivity and multi-dimensional functionality. It was developed a wide range of MEMS tactile sensors mainly based on silicon micromachining [3]. MEMS tactile sensors are generally classified based on detection mechanisms [4],[5]. These include tactile sensors like piezoresistive, capacitive, piezoelectric and optical [6],[7],[8],[9],[10],[11]. Of these, the piezoresistive type is widely used because they are easy to manufacture and have a low cost price. Due to difficulties of applications of tactile sensors on a rigid body, recent reports have focused on MEMS tactile sensors based on polymers [12],[13]. This article reviews the recent research outcomes concerning resistance-type strain sensors as touch sensor solutions suitable for increasing the skills of a robotic hand [14], in order to better manipulate objects and perform operations. The analysis of last developments in the area shows that resistive techniques are still the predominant choice for tactile detection and currently are estimated more than 50 technologies to manufacture proper resistive materials [1].

Acceptance of pressure sensors in many application segments will add on to their consumption in the future. Robotics today is constantly expanding from a fixed medium, of a production line, for more complex environments such as homes, offices and hospitals [15]. In order to ensure safely efficient interactions between the robot and humans, several detection capabilities are necessary for robots, such as visual detection and auditory senses, detection of touch or temperature [16]. For detecting the physical contact with humans or the environment, is essential for robots to have large tactile sensing areas into their flexible artificial leather. Different approaches to achieve sensitive touch based on surface micromachining have been proposed by several research groups. Typically, MEMS sensors are used for final "hands" of robots, so that they can accept/read ("feel") a contact force or pressure when touching objects [10].

"For robots, the final frontier is not space, is the living room" [17]. The new application domains require versatile, autonomous, intelligent robots, which can interact with humans and their broad range of instruments, tools in real-world environments. To perform increasingly better human-related functions are needed robots able to perform increasingly better human type handling tasks and the current state of research in robotics is moving from the task of grasping towards the advanced handling capabilities such as those grips to-hand rotation and translation [18]. To act intelligently in unstructured and changing environments, robots will need to be able to

manipulate objects with simultaneously detecting and understanding of their environment. To achieve this, the robots need an interface to provide information about the forces and positions of all points of contact between them and the objects they interact with. A key issue in robotics community today is therefore the development of artificial leather interfaces, fully distributed with tactile sensors [10]. Tactile detection in robotics is defined as continuous detection of variable contact forces [19]. This information can be used to determine whether the robot is in contact with an object, which is the configuration of the contact, the grasping stability, and which is the force's feedback for the robot control. In addition, it is expected that tactile information's are used to analyse object manipulation to better understanding and optimize handling techniques so that to rise further versatility, skills and performance of the robot [10]. The study and the measurement of the human's forces and their actions of gripping are important in a variety of contexts [20]. In case of young children [21], these studies and measurements can provide an understanding of the neuromotor development and the pathological disorders, the latter representing the functional and operational requirements that are not fully covered by current sensing technology. New approaches for measuring how gripping action occurring in young children is based on toys with sensors for the natural development environment [22]. One of the major disadvantages of Minimally Invasive Surgery (MIS) is the lack of the tactile contact of the surgeon with the operated area. It is important to measure the degree of local soft tissue during minimally invasive surgery in order to identify and avoid any damage to the complex tissue attached to the clamps (clamping jaws) endoscopy [23]. One way to display to the surgeon the measured degree of softness is a graphical method [10]. In this paper, it was reported a new touch sensor. As reported in the paper, the tactile sensor consists of a network of four soft sensors that are integrated in the clamping jaws of a modified commercial type endoscope. Each sensor, in the degree of softness, is composed of two piezoelectric films of poly-vinylidene fluoride polymers (PVDF) [10]. The experimental results showed that the sensor system works well as a sensor for monitoring local haptic properties of the skin [10]. That control system sends tactile signals from clamping system to a computer using the developed signal processing and display computerized system. Visual data have demonstrated the degree of local soft tissue grabbed by clamping system [10]. Cheng et al. (2011) [24] presented highly flexible artificial leather at twisting by distributing a conductive polymer on a grid of electrodes. Developed conductive polymer was a composite material, respectively a mixture of PDMS and a variety of conductive filler materials (copper, carbon black, cyclohexane and silver particles). Detection electrodes were produced by winding the copper electrode around a nylon fibber. Advantages of this approach include: increased robustness due to substrate material which is a polymer of low cost; low complexity manufacturing of low-temperature processing through the use of SU-8; the improved transfer of mechanical stress from the membrane voltage detector mechanics [24]. Have been investigated the mechanical problems, such as mechanical stress and strain distribution by (Lee & Lee, 2005)[16]. Other

potential applications of this sensor include detection of small organic tissue, at the end of a catheter or a tele-manipulator finger in endoscopic surgery.

## 2. Elastomeric conductive composites

The composites made of an elastomeric polymer material and a conductive filler present piezoresistivity and they are very good candidates for tensoresistive sensors [8],[25],[26]. Crosslinking silicone elastomers at room temperature (RTV SE - Room Temperature Vulcanized Silicone Elastomer) are materials suitable for obtaining flexible conductive/semi-conductive matrix composite [27] because they have low viscosity and cures at room temperature and at low pressure. The current state of research in developing polymer-based sensors for biomedical applications is reviewed in another two papers [3],[13]. This type of sensor depends on the parameters of interest, such as skin temperature/tissue, the force exerted by the tissue/blood vessel during surgical procedures and the presence of the biochemical components such as glucose and cholesterol. Conducting Polymers (CP) have excellent electrical properties, chemical and mechanical useful for designing efficient, versatile and with real-time response biosensors [13]. Thin metal markers, which act as electrodes for polymer-based touch sensors, are most vulnerable to large deformations, distortions, which occur in particular when it is necessary to integrate on the complex surfaces of the sensor unit. Therefore, research efforts are directed towards increasing the reliability and robustness of these markers. Hu et al. (2007) in [28] reported a flexible sensor that detects force and temperature simultaneously. The sensor is composed of a composite (multi-walled carbon nanotubes dispersed in polydimethylsiloxane (PDMS)) and interconnections from liquid metal. Sekitani et al. (2008) proposed a flexible material, conductor, which may be uniaxial and biaxial stretched by 70%, without causing mechanical or electrical damage [29],[30]. Sensor material was developed by coating a PDMS rubber base with a composite containing single wall carbon nanotubes [22].

Advanced technologies and improvements in the material properties of CP's will allow integration of CP's as sensors for applications in various fields of biomedical engineering (prostheses, implants with feedback systems, biochips for personalized medicine, etc.) [31]. In another paper, (Yousef et al., 2011) [10], it is concluded that a frequent choice of pressure sensitive materials are elastomers that are enriched with conductive filler particles. When an external force is applied to the sensor, deforming elastomeric composite layer, the electrical resistivity is changing, according to the type of conductive particles, to their percentage in the elastomer's volume and the stiffness of resulting material. Elastomers are highly elastic materials which makes them excellent candidates for application to curved surfaces [8] and moving parts. Moreover, using a soft material that imitates human skin increases the grip ability. However, the applications are mainly limited to the pressure detection since these composites shows an isotropic electrical conductivity. Other disadvantages of this kind of sensors include hysteresis, noise and limited dynamic ranges [32]. In one paper [33], it is shown how the conductive elastomer

disks, a poly-siloxane elastomer (silicone rubber) with electric conductive particles from artificial graphite [34] (CSA), are attached directly to the electrodes on the surface of a flexible circuit board (PCB - Printed Circuit Board), forming a (32×32) network of sensors. The small disks of conductive elastomer are bonded on electrode pairs individually avoiding cross-talk between each tactile sensing element. In addition, the electrodes include structures that act as temperature sensitive plates. A normal force of 5-10 N was used to press the solid disks onto a matrix network with and the pressure distribution configuration (see Fig. 1), was presented as tactile array with a spatial resolution of 5 mm.
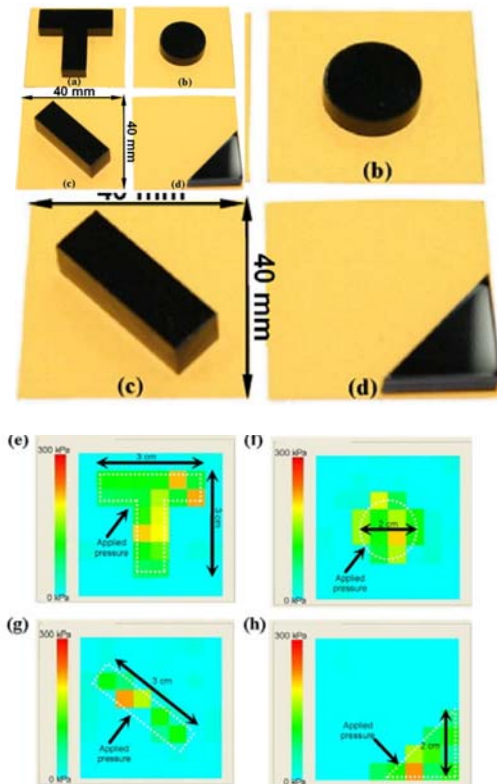


*Fig. 1 Pressure distribution measurements of solid stamps that are applied with a normal force onto the sensor arrays. The solid stamps are shown in (a–d), and their corresponding tactile images are shown in (e–h)[33].*

Other paper [24] presents a method to obtain a twistable and reliable artificial skin by using spiral electrodes as sensing electrodes. The spiral electrodes were made from copper wires wound around nylon lines (see Fig. 2) thus allowing higher degrees of stretching and bending.

The tactile sensing elements were formed by dispensing conductive polymer on the spiral electrodes in the intersection points of a mesh of the spiral electrodes. A network of 8×8 tactile sensing arrays with areas of 10mm ×10 mm and 20 mm × 20 mm was demonstrated. The pitch distance between each sensing element was 2.5 mm. At a pressure grater than 450 kPa, the electrical resistance of the conductive polymer reaches a steady value.
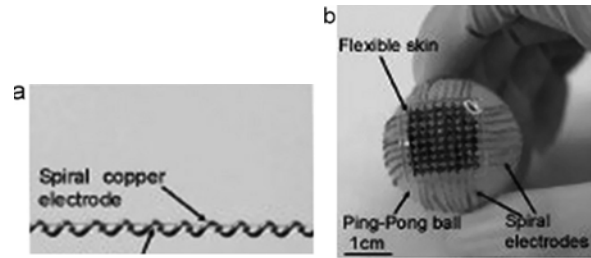


*Fig. 2. (a) The fabricated extendable spiral electrode. (b) The sensor array stretched over a ping pong ball.* [10].

In another work [35], the sensing networks are extended to a matrix of (16×16) array covering an area of $160×160$ mm$^2$ on a mannequin arm. The tactile sensitive elements shows the same sensitivity as in [24], but with a substantially lower spatial resolution. According to one paper [36], regarding the fabrication of a sensitive skin consisting of thousands of pressure sensors, means that the number and complexity of pressure sensor arrays increases and aas a result the flexible switching matrix that cannot be realized with conventional silicon-based transistors since there would be a loosing of mechanical flexibility. One solution, could be the integration of flexible organic networks of field-effect transistors (OFETs) in a pressure-sensitive layer based on PDMS. Organic field effect transistors OFET's can be deposited, on flexible plastic sheets using on large areas by various deposition techniques, with small costs. A (32×32) sensor array with a spatial resolution of 1 mm and integrated OFET's was successfully demonstrated (see Figs. 3 and 4) for an output signal of the sensor in the range of 0-30 kPa applied pressure.

Concerning to the development of mechanical spectroscopic stress sensors, a significant research has been focused on modifications of the mechanical stresses induced in the Raman spectra for a wide range of materials, both organic and inorganic [10].
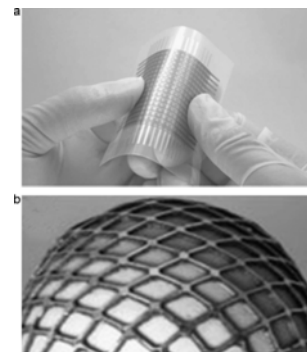


*Fig. 3. (a) Flexible PDMS-based pressure sensor network with an integrated OFET matrix used for switching as read-out electronics [36]. b).Mechanically processed netmaterial containing pressure and temperature sensor network with integrated OFETs [37]. The net material is stretched over an egg.*

In this paper [18] authors present the manufacture of a flexible strain gauge (3×3) sensor array (Fig. 4) using

conductive polymer solutions with complementary materials, including carbon nano-fibbers and multi walls carbon nano-tubes.
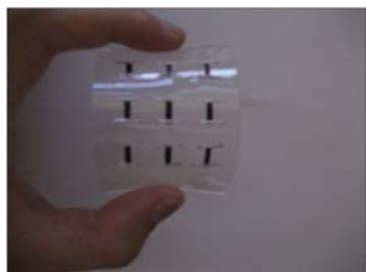


*Fig. 4. (3x3) Flexible strain sensors network matrix [18].*

The proposed method can be applied to fabricate flexible and reliable network matrix of strain sensors [22] for mechanical and electromechanical applications and bio-applications (Fig. 6) [38]. Other types can be made of silicone elastomer composites (SE) with conductive fillers (nano-particles from carbon black (CB)) and dilution/ plasticizer agents (*e.g.* dimethyl silicone oil (SO)) for potential applications in the strain detection [27].
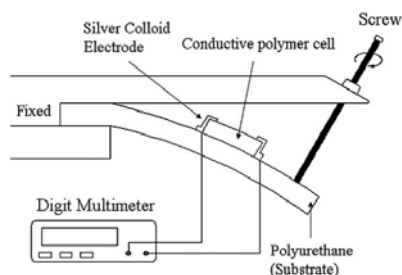


*Fig. 5. Measurement scheme for the characterization of flexible strain sensors (Chang et al., 2010).*

In order to stabilize the composites heat treatment was used, and thermo-gravimetric analysis confirms the good stability of the composites after the heat treatment. It was studied the effect of carbon black addition on the electrical properties of the composites and the percolation transition has been found in the range of (0.5-2.5)% by weight carbon black addition. I-V characteristics and analysis by impedance were used to explain the mechanisms of conduction of the composites. The presence of dimethyl silicone oil reduces the elastic modulus (Young's modulus) of the composites without reducing their elongation at break. Characterization of the electromechanical properties of the composites demonstrates that in the post-percolation process, a composite with 9.0% CB by weight has an adequate sensitivity to mechanical tension, good repeatability and linearity, as well as slight dependency on the rate at which the mechanical tension is applied, so that the composite can be used as flexible strain sensors for measuring large deformations [18],[27].

Electrically conductive elastomeric composites have been extensively investigated for smart applications: electromagnetic shielding structures, for electrostatic charge dissipation, for electronic switches, for self-

regulating heaters and sensors. The advantages of these materials include: excellent flexibility, low weight, high stability and safety in the environment, and lower production costs. One of the most promising applications is mechanical tension sensor which can measure repeated mechanical stress or displacements, which is an important element for portable electronic devices and human-machine interaction devices [39]. These flexible strain sensors requires the following basic material properties: base materials sensitive to mechanical stresses, a large range of mechanical tension measurement, good repeatability of the electromechanical response, predictable effect with temperature, predictable effect of the rate of application of the mechanical tension, high resistance to tiredness for medium and long term, chemical stability and low Young's modulus, which should be comparable with human skin. These sensors are a new type of strain detection sensors unlike those currently used to detect mechanical tension such as those based on metal or those based of optical fibbers that cannot provide the required performance [18],[27]. Elastomers filled with electrically conductive materials present piezo-resistivity and they are promising candidates for such sensors. Studies include use of natural and synthetic rubbers, thermoplastic elastomers and silicone elastomers as matrix materials. However, for vulcanization, these materials require elevated pressure and temperature, which significantly limits their application in the textile industry, because they are easily damaged in such conditions. Silicone elastomers, vulcanized at room temperature, have a low viscosity and the vulcanisation temperature and pressure with a good biocompatibility, excellent mechanical properties, chemical and thermal resistance, what make from these materials a promising flexible and conductive composite matrix [27]. Of the three major groups of conductive materials used as the additional material, such as complementary metal materials, additional carbon materials and polymers with the intrinsic conductivity, the second group is the most attractive because of low density, high environmental stability and the good chemical stability. For applications such as mechanical stress sensors have been studied conductive composites with graphite powder and carbon fibbers. However, it was necessary a higher loading of additional material but the sliding wear behaviour of graphite and carbon fibber led to fragility of composite's and poor repeatability of electromechanical responses to cyclic mechanical tests [27]. Although composites with carbon nanotubes [40] and graphene can be used to detect mechanical stress applications, a light weight with complementary material, the high price, the uncertain safety effects on humans and the unavailability of large-scale industrial production prevents their use, in report with conductive carbon black production with low price [27]. Nowadays, there are great challenges for the mixing of a silicone elastomer with a high amount of carbon black in the region after the percolation threshold, because the viscosity of the mixture increases dramatically with increased loading of additional material (Fig. 6-7) [41],[42][43],[44],[45][46]. One possible way to solve the problem of reducing the viscosity [45],[47] of the mixture and to increase dispersion of carbon black particles that the mixture is the use of organic solvents, such as hexane.

However, the Young's modulus of the composites thus obtained has a significant increase, leading to composites with high rigidity, and this is undesirable.
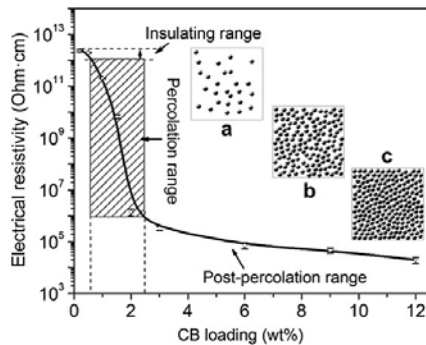


*Fig. 6 .The ratio of the electrical resistivity and carbon black (CB) load. The annotations of the figure show (a) the isolator domain, (b) the percolation domain and (c) the post-percolation domain [27].*
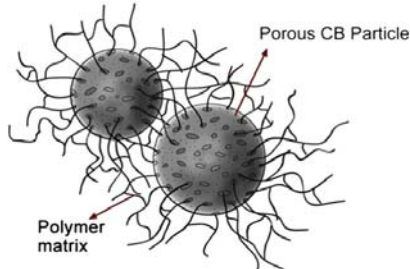


*Fig. 7. There is a schematic view of the matrix material with the molecules which enter the porous particulate carbon black (CB) [27].*

Conductive composite materials with addition of supplementary carbon black in the percolation area have a high sensitivity [45]. However, significant changes with several orders of magnitude of the electrical resistance, in the small interval of mechanical stress, make their measurement to be difficult. In this paper [45], were manufactured silicone elastomers composites with nanoparticles from highly porous carbon black like complementary materials using dimethyl silicone oil (SO) as diluent and plasticizer. The electrical properties, mechanical and thermal properties of composites have been studied experimentally. Were identified their sensitivity, linearity and desired working range with consideration of their potential applications as flexible mechanical tension sensors [27]. Low structured materials, but highly porous (more than min.80%) carbon black nano particles (Carbon ECP600JD, from Akzo Nobel, with a diameter of about 30 nm) was heated at 80°C for 24 hours to remove moisture. The specific surface area of carbon black particles was around (440-510) $m^2$/100g, value expressed with di-butyl phthalate absorption (DBP). A silicone elastomer (ELASTOSIL LR6200 A and B, from Wacker Chemie AG, Germany) was used as delivered. As solvent, was used dimethyl silicone oil, non-toxic, with a kinematic viscosity of 5.0 $mm^2$/s at 25°C (Che Scientific Co., Hong Kong) to reduce the viscosity of the paste of the mixture and as plasticizer, for reducing the elastic modulus of the composites. Connecting conductive wires from

silver coated nylon were used between the measuring equipment and the conductive composite. The electrical resistance of the samples, without mechanical tension, was measured with a digital multimeter by the method of two-wire resistance, while for measuring higher resistance was used the resistance insulators tester. Volume resistivity, $\rho$, was calculated using the equation $\rho = R \cdot w \cdot d / l$ where R is the resistance ($\Omega$), l, w and d are the length, width, respectively, the thickness of the samples. Based on the resistivity changes were defined three intervals depending on the amount of carbon black added, from (0-0.5) % wt., at 2.5%wt and over the 2.5%wt (Fig. 6), to which, consequently, the conductivity shows the insulating, percolation and after percolation regimes [27]. In other paper, Hu et al., [48] investigated results of the behaviour of the sensor subjected to both at tension and compression. Both types of results, the numerical and experimental results, indicate that higher tunnelling resistance or a higher ratio of tunnelling resistance to the total resistance of the sensor lead to a higher sensitivity of the sensor assembly [27]. Essentially, the piezoresistivity observed in the strain gauge sensors made from composites of polymer and carbon nanotubes (CNT) can be attributed mainly to the conductive network changes due to the mechanical stress following: the reduction or loss of the contact number between the fibrils of the complementary material, loss of the tunneling effects in the surrounding areas of complementary material fibrils and conductivity changes in deformed CNTs. More recently, was developed a three-dimensional statistical model consisting of a network of resistors, model that includes the effect of a tunneling between the neighboring carbon nanotubes CNT and reorientation of nano-fibers subjected to external mechanical stressIt was found that the tunnelling effects are the main operating mechanism of a sensor, under conditions of low mechanical stress, as compared with the other mechanisms mentioned above. The model was verified by experimental results [48]. Several solutions have been proposed to improve the sensitivity of the sensor, such as (1) the use of a less CNT content, close to the percolation threshold, (2) lower heat treatment temperature, (3) more stirring or mixing ratio, (4) the small diameter of the filling material and a larger height of barrier array, and (5) higher electrical conductivity of the additional material [27]. The electrical conductivity of the composite increases as the conductivity of additional nanomaterials increases (Fig. 8), leading to a higher ratio of the tunneling resistance to the overall resistance of the composite [48],[49].
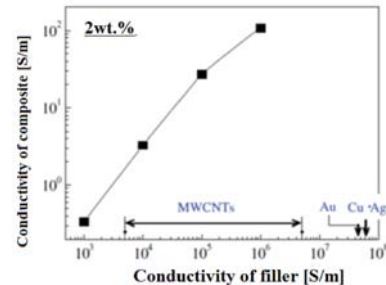


*Fig. 8. The electrical conductivity of the composite material depending on the electrical conductivity of the additional material (numerical results) [48].*

In the paper [50] the authors describe a wireless measurement system of the compresion/relaxation stress based on pressure sensitive sensors developed with the aim of detecting the compression stress and to monitor the relaxation stress of the flexible surfaces of a furniture during the transportation and/or installation [50]. Flexible network matrix sensor, sensitive to mechanical stress (pressure), was made using a silicone rubber-based composite material with carbon black filler. For performance evaluation, the wireless system for measuring the mechanical tension, integrated with the array of sensors, has been tested at a compression strain, in the range from 0 Mpa to 3MPa. Experimental results showed that the fractional change in electrical resistance of the mechanical tension sensor, pressure sensitive, varies linearly and reversible with the request to compression and its fractional variation goes up to 355%, at uniaxial compression; the rate of change of electrical resistance can track tension at relaxation and can give a credible measurement in effort into the relax procces. The relationship between the size of the input (compressive strain) and output (fractional change in electrical resistance) pressure sensitive sensor is $\frac{\Delta R}{R_0} = \sigma \times 1,2 MPa^{-1}$.

The wireless measuring system the compression pressure may be used to obtain a sensitivity of 1.33 V/MPa of stress at a resolution power (force) to 920.3 Pa. Recently developed wireless strain measurement system, integrated with pressure-sensitive sensors with silicone rubber and carbon black complementary material, has advantages such as: high sensitivity to mechanical stress, high resolution to mechanical effort, simple circuit and low power consumption [50]. To improve the accuracy of installation and to ensure safety in keeping a protective supplies [51], it is essential to detect tension at compression and to monitor mechanical tension at relaxation between two surfaces of a flexible film as insulation stuffed. There are two stages in the experiment. In the first experimental phase, the sample was compressed instantly from zero pressure up to a given pressure P, by the application of weights over the electrode. Then, the pressure P was kept invariant for 1800 s. In the second stage of the experimental sample was decompressed instantly at a given pressure P at zero pressure, with the release of the weight of the electrode. Then, the pressure was maintained invariant zero for 1800 s [51]. In the paper of Hu et al., [48] mechanical strain sensor was fabricated from a polymeric nanocomposite with multi walled carbon nanotubes (MWNT-Multi Walled Nanotube) as complementary material-dispersed phase. The piezoresistivity to of this mechanical tension nanocomposite sensor was analyzed by a improved statistical model of three-dimensional network of resistors, incorporating the tunneling effect between adjacent carbon nanotubes and a shift pattern of the fibers [48]. For the most part, the numerical results are in agreement with experimental measurements. Compared with traditional mechanical stress transducers, sensors of nanocomposite materials which can be obtained have much higher sensitivity when the volume fraction of carbon nanotubes CNT is close to the percolation threshold. For a small volume fraction of CNTs is observed in both experimental and numerical simulation, a low nonlinear piezorezistivity.

The tunneling effect is considered to be the main mechanism of the sensor under low mechanical stresses [49],[51][52],[53],[54]. At low mechanical stress, electrical resistance variation is dominated by the tunneling effect between neighboring carbon nanotubes, instead fracture of conductive network [48]. In the case of pressure sensitive materials from elastomers with conductive filler particles, when an external force is applied to the sensor, deforming composite elastomer layer, (Fig. 10), the electrical resistivity is changing, according to the type of conductive particles (Fig. 11), their percentage by elastomer volume and the stiffness the resulting material. Since elastomers are highly elastic that makes them excellent candidates for application to curved surfaces and moving parts. In the work of (Huang, Tsai, & Lai, 2010) [55], a new tactile sensor is analysed and verified by intensive experiments. By using flexible micro bridge in console on which are deposited strain gauge layers (transducer/sensor strain gauge) (Pt/Ti), the corresponding mechanical stresses induced can be detected and converted into variations in electrical resistance. According to applied mechanical stresses either applied shear the micro-touch detection, the sensor may detect a normal mechanical stress of up to 250 kPa and a shear stress for up to 35 kPa. In the addition, because it is made of PDMS elastomer, which has a high bio-compatibility, the touch sensor may be used to direct contact with the human body. Finally, the effectiveness of the touch sensor is verified by experiments using a micro-manipulator, a high-resolution microscope and a force sensor for calibration [55]. Intrinsic conductive polymers (ICP-Intrinsically Conducting Polymers) have a very flexible chemical structure that can be modified to achieve desired electronic and mechanical properties. Since the ICP have the ability to efficiently transfer electrons produced by biochemical reactions, they have been widely used in biosensors in the form of transducers forming an intermediate layer between the biological sample and the electronics used to read of signal. They are also known to be compatible with biological molecules in a neutral aqueous solution. For the same reason, ICP have attracted attention as a suitable matrix for immobilization of biomolecules. Several studies have explored the unique properties of ICP type materials to produce a wide range of biosensors to measure critical analysis relevant to clinical diagnosis [49]. Therefore, there appeard a new class of materials called conductive polymer composites (CPC-Conducting Polymer Composites) [56], that was opening up exciting new applications in several areas, including bioelectronics. CPCs typically consist of a combination of one or more conductive polymers and conductive filler materials, distributed throughout the matrix polymer [57]. It was thus created a new class of conducting organic polymers, also known under the name of intrinsic conductive polymers (ICP). ICP containing monomers capable of acquiring a positive or negative charge, by oxidation or reduction, which, in turn, contribute to the electrical conductivity of the ICP. Some examples of ICPs are: polyacetylenes (PA), polypyrrole (PPY), polythyophenole (PT) and polyaniline (PANI) [54]. *Note: A polymer with intrinsic conduction should be distinguished from a conductive polymer composite and a solid polymer electrolyte (IUPAC definition).*
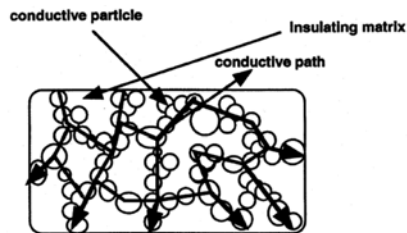
*Fig. 9. Three dimensional conductive paths in compositea without pressure [54].*
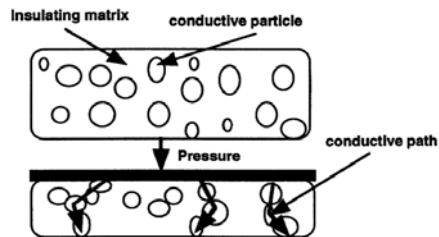


*Fig. 10. Formation of conductive paths in composite by pressing [54].*

## 3. Conclusion

These flexible strain sensors requires the following basic material properties: base materials sensitive to mechanical stresses, a large range of mechanical tension measurement, good repeatability of the electromechanical response, predictable effect with temperature, predictable effect of the rate of application of the mechanical tension, high resistance to tiredness for medium and long term, chemical stability and low Young's modulus, which is comparable with human skin.

Different types of materials used for tactile sensing includes silicon-based piezoresistive [58][59][60] or capacitive sensors and polymer-based piezoelectric, capacitive or piezoresistive sensors [61][62]. Recently researchers have explored the possibility of using composite-material sensors by combining both silicon and polymers, examples of which includes embedding of silicon sensing elements in polymer skins, packaging of silicon-based sensing devices in protective casing of polymer layer [63], etc. Silicon-based tactile sensors have proven to provide high sensitivity [64],[65] high spatial resolution and ease of integration into electronic devices [31].

In the modern world, the need for pressure sensors is constantly evolving and growing. According to a new market research report [1] pressure sensors market value was $ 5.11 billion in 2011 and is expected to reach $ 7.34 billion in 2017 , an annual growth rate ( Compound annual growth Rate - CAGR) estimated at 6.3 % during 2012-2017 .

Demand for reliable sensors, high performance and low price is also increasing leading to development of new materials and technologies.

Piezoresistive nanocomposite materials are the new materials used in the development of pressure sensors [66]. A material is piezoresistive if its electrical resistivity changes as the application of mechanical stress [67][68][69]. By improving material properties, structural nanocomposite material can act as a „smart" sensor because piezoresistive effect gives them the opportunity to „auto-detect" the request or mechanical contact for varying electrical resistivity.

There are advanced materials market demands for flexible large area piezoresistive sensors that can be incorporated in various sensing applications. Semi - conductive polymer composites, nanostructured, provides attractive alternatives for developing new generations of flexible large piezoresistive sensors due to superior electrical and mechanical properties.

Having in mind the ideea of versatility and low cost production of tensoresistive pressure sensors with high performance, good stability and sensivity in the required operating conditions, a new class of advanced polymeric nanocomposite materials was developed through researche performed at INCDIE ICPE-CA. The materials were developed specifically for the measurement of pressure [60] and sensors for perimeters security, including monitoring against intruders with piezoresistive sensor in automobile and occupied enclosures.

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*Corresponding author: leila_zevri@yahoo.com