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Potential of adaptive neuro-fuzzy inference system for contact positions detection of sensing structure

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ABSTRACT

Tactile sensing is the process of determining physical properties by contact with objects. Here, a novel methodology of an adaptive neuro fuzzy inference strategy (ANFIS) for detection of contact position of a new tactile sensing structure was proposes. The major task is to investigate implementations of carbon-black filled silicone rubber for tactile sensation; the silicone rubber is electrically conductive and its resistance changes by external deformations. The sensor-elements for the tactile sensing structure were made by press-curing from carbon-black filled silicone rubber. The experimental results were used as training and testing data for the ANFIS network. The ANFIS network is used to approximate correlations between contact point locations of the sensing structure. The simulation results presented in this paper show the effectiveness of the developed method. This system is capable to find any change of contact positions and thus indicates state of the current contact location of the tactile sensing structure. The behavior of the use silicone rubber shows strong non-linearity, therefore, the sensor cannot be used for high accurate measurements. The greatest advantage of this sensing material lies in its high elasticity.

1. Introduction

In the last two decades, robotics researchers have worked to create an artificial sense of touch to give robots some of the same manipulation skills that humans possess. An artificial skin for covering the whole body of a humanoid robot was developed in [28,7]. Further, a flexible and stretchable tactile sensor was proposed which can detect touch and it reacts by using static electricity and electrostatic induction [48]. In [40] tactile sensors were developed based on uses of conducting polymers for construction of pressure sensors that are designed to be used in robotics for artificial hands. Some authors proposed a tactile sensor skin that is based on a tactile sensing method where a sensor element acquires not only a contact force, but also a contact area using the nonlinear elasticity [16]. Another design of a sensor system, which was proposed in [50,24], could easily be mounted onto the skeletal structure of an anthropomorphic robot hand. In [25,4] a soft areal tactile sensor was presented, made of pressure-sensitive conductive rubber without any wire or sensing element in the tactile region. Further development of the tactile sensing structure led to a sensor which utilizes a polyamide-based packaging scheme to incorporate a silicone-based sensor in flexible skin which facilitates use at the skin/load interface [5]. In [8] a design of fully integrated tactile and 3-axis force sensors with embedded electronics was presented. A method for recognizing objects using tactile information was developed in [38]. In [26] was proposed a design of homogeneous flexible and stretchable robot skin based on carbon-black-silicone and conductive fabric that can sense multiple contact locations as well as applied pressure. A mechanically

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compliant tactile sensor was developed in [29] through direct-write (DW) deposition of a flexible conductive nanocomposite embedded between flexible polyurethane materials. Tactile sensing system on chip was investigated in [41]. Fabrication and calibration of a highly compliant mechanism to be used as an artificial skin sensor was described in [35]. A modular expandable capacitive tactile sensor using polydimethylsiloxane elastomer was demonstrated in [27]. In paper [17] was proposed and demonstrated a transparent and flexible capacitive tactile sensor which is designed for multi-touch screen application with force sensing. Paper [18] provided a review of the current state-of-the-art in tactile force and pressure sensing within the specific context of dexterous in-hand manipulation. In work [39], a functional prototype of a microfluidic normal force sensor that uses a liquid metal alloy for its internal circuitry was created. The novel use of conductive fluids as deformable capacitive plates and wire paths offers significant advantages over the use of standard solid components such as robustness to cracking and fatigue. In paper [9] was presented a novel design of highly twistable tactile sensing array where conductive polymer is used as the tactile sensing elements. The basic aspects related with tactile sensors, including transduction techniques were revisited in [37].

The aim of this paper is to investigate implementations of carbon-black filled silicone rubber for tactile sensation; the silicone rubber is electrically conductive and its resistance changes by external deformations. These features make this material suitable for developing force sensors. Since it is nonlinear system it is suitable to apply soft computing methodology for estimation of contact positions of the tactile sensing structure [42,44,6,23,20,30,10].

The key goal of this investigation is to establish an approximated adaptive neuro fuzzy inference system (ANFIS) for detecting of the contact positions of the tactile sensing structure. That system should be able to estimate the contact position. ANFIS [19], as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers for modeling [14,43,32,34,31,2], predictions [15,21,46] and control [22,36,33,47] in various engineering systems. The basic idea behind these neuro-adaptive learning techniques is to provide a method for the fuzzy modeling procedure to learn information about data [1,11,45]. The ANFIS is one of the methods to organize the fuzzy inference system with given input/output data pairs [49,13]. This technique gives fuzzy logic the capability to adapt the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data [3].

2. Materials and methods

2.1. Sensing structure design

The sensors were made of carbon-black filled silicone rubber (Elastosil® R570/50, Shore A 50) by press-curing process. ELASTOSIL R solid silicone rubber are synthetic rubbers which differ in structure from conventional elastomers. ELASTOSIL R grades are based on the chemistry of silicone – and share the same outstanding properties. This material are ade of three componentes: polymers, filler and additives. Fillers are needed to fill the gaps between the polymers and support the network from within. The type, quantity and composition of the filler can vary and this determines to a large extent the properties exhibited by the rubber or elastomer.

Electrical resistance changing of the sensor-elements was measured with the help of a special compression-tool and electrodes attached to the end of specimens during the vulcanization of the silicone rubber. The electrodes were made from soft copper weave. This net can make good electrical contacts because it has large surface and good conductance. Wires were soldered on the electrodes to connect to the measurement instrument.

A tool was designed for production of the sensor-elements. In the beginning of this production process, the cavities in the tool were filled with raw carbon-black filled silicone rubber (Elastosil® R570/50, Shore A 50). After that, electrodes were positioned into the proper position and two parts of the tool were tied together. The next step was press-curing of the filled material at $T = 180\,°C$ and pressure at $p = 26$ kN for about 30 min, after which the tool was cooled. Following the cooling process, the formed specimens were extracted from the tool. In order to achieve the optimum electrical properties, it was important to post cure these specimens for at least 4 h at 200 °C after molding. In the end of the production process, the initial resistance of these sensor-elements was measured.

After the production of the sensor-elements, the next step was design of an experimental tactile sensing structure. This structure consists of four sensor-elements and one elastic non-conductive silicone sheet placed above them. This sheet was divided into four equal sectors in each direction for an easier determination of the loading position of the external force (Fig. 1). The area of the whole sensing structure was $40 \times 40\ \text{mm}^2$ and of each sector was $10 \times 10\ \text{mm}^2$. In some other investigations there were other arrangement of the sensors, e.g. in [51] was size and configuration of the force-transfer columns are symmetrically determined by tetragonal area partitioning for minimal influence on strain gauges under the neighbor column.

2.2. Experimental setup

To determine mechanical and electrical properties of the sensing structure and to acquire experimental training and checking data for ANFIS network many experimental measurements were executed. Each test was repeated because the first graph often differed from the others. To evaluate how stable the behavior of the silicone material was many repetitions of the test on many sensor-elements were made. To establish the correct behavior of the conductive silicone rubber, it was important to see how compression strain and force correlated with electrical resistance.

To test the tactile sensing structure, laboratory experiments were conducted using the LabVIEW virtual instrument and National Instruments BNC-2120 card. A procedure was developed that relied on monitoring and