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Testing and Characterization of Multilayer Force Sensing Resistors Fabricated on Flexible Substrate

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Abstract: This paper presents design, fabrication and characterization of force sensing resistors (FSRs) which can be used in many applicable devices in medicine, rehabilitation, robotics, dentistry, etc. They consist of printed interdigitated electrodes on flexible substrate, an adhesive spacer and a carbon based sensing layer. Four types of FSRs were fabricated with different designs of active area. Measurement setup for testing and characterization has been developed in laboratory conditions and represents a device for precise implementation of a controlled force on FSRs. The characteristics of FSRs - the resistance as a function of applied force and temperature as well as the voltage as a function of applied force are presented. The obtained resistances were in the range of tens of Ohms for a wide range of applied force (1 N – 65 N).

Keywords: Electronic component; Materials; Force Sensing Resistor (FSR); Flexible substrate; Characterization

Preizkušanje in karakterizacija večslojnih uporovnih senzorjev sile izdelanih na fleksibilnih substratih

Izvleček: Članek predstavlja dizajn, izdelavo in karakterizacijo uporovnih senzorjev sile (FSR), ki se jih lahko uporabi v številnih aplikacijah v medicini, robotiki, zobozdravstvu… Sestaljeni so iz tiskanih prepletenih elektrod na fleksibilnem substratu, lepljivim distančnikom in senzorsko plastjo na osnovi ogljika. Izdelani so bili štirje tipi senzorjev glede na obliko aktivne plasti. Vzpostavljeno je bilo merilno in karakterizacijsko orodje v laboratorijskem okolju, ki omogoča natančno implementacijo kontrolirane sile na FSR. Prikazane so karakteristike FSR – upornost kot funkcija sile in temperature ter napetost kot funkcija sile. Upornosti so v razredu ohmov za široki razpon uporabljenih sil (1 N – 65 N).

Ključne besede: elektronske komponente; materiali; uporovni senzor sile; fleksibilen substrat; karakterizacija

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1 Introduction

Force and position sensing are an integral part to a wide range of measurements. Force sensing resistors (FSRs) have been used in a number of force sensing applications in many fields, such as medicine, rehabilitation, robotics, etc. [1-3]. FSRs are devices that allow measuring static and dynamic forces applied to a contact surface. Their range of responses is basically depending on the variation of its electric resistance. The FSR is usually a flat, flexible device that exhibits decreasing electrical resistance with increasing force applied normal to its surface. Some of the most popular commercial types of FSRs are: FSR Interlink Electronics [4], FlexiForce-Tekscan [5] and PS3-LuSense [6] sensors. A commercial FSR encompasses of two layers, namely a conductive surface and the printed electrodes. Both are facing each other which allow a contact between two surfaces. This results in the conductive layer of the printed electrodes short circuit to reduce the electric resistance upon force pressure. Usually, the resistance dropped from 1 MΩ to 10 KΩ for the applied force is in the range from 1 N to 10 N. FSRs are available in a few different shapes such as round, square and strip and their small thickness and mechanical flexibility allow them extensive applicability. Force sensors are widely used in the robotic field, particularly for robot interaction control application. A study has been conducted in [7] to utilize the Tekscan Flexiforce and the Interlink FSR sensors in robotic and biomechanical applications. Two different set of experiments (the hardness detector system and the force-position control system) were carried out in [8] to test the effectiveness of the Flexiforce and Interlink sensors. Characteristics of three types of force-sensing resistors (Interlink FSR - Standard 402, FlexiForce - A201, LuSense PS3 - Standard 151) were identified in [9] for usage in a refreshable and portable E-Braille device that can assist the blind and visually impaired persons. An effective technique that improves reliability and accuracy of measuring compression force using FSRs (Interlink Electronics) was presented in [10], for biomedical and industrial design applications where measurement of finger and hand force are needed. In the paper [11], authors reported FSRs that are adequate to be part of wearable components. Authors focused on the sensing technologies that are compliant with the integration inside garments or other kinds of clothing (i.e., shoes, backpacks). Two different force sensitive resistors: FSR 406 (produced by Interlink Electronics) and A401 (from Tekscan) were evaluated in [12], while demonstrating gaits of healthy individuals through their loading behaviour. The flexible tactile force sensors presented in [13], were fabricated using a moulding process of a composite material, which is a mixture of two components: conductive ink and silicon elastomer, expressing good linearity and repeatability. A system with force sensors (Tekscan FlexiForce), which are placed on the hands rather than on objects, allowed improvements in versatility and spatial resolution to be made in measuring forces developed by human hand, was presented in [14]. The system has been successfully used to measure forces involved in a range of everyday tasks such as driving a vehicle, lifting a sauce pan, or hitting a golf ball. A wearable arm device that equipped with a monitoring system for post-stroke rehabilitation was designed and proposed in [15]. The device was equipped with an Interlink FSR sensor along with other sensors such as flex sensor and accelerometer. In the paper [16], FSRs were used to detect the transitions between five main phases of gait for the control of electrical stimulation while walking with several children with cerebral palsy. The paper [17] described testing of a bite force sensor based on force sensing resistor. The sensor surfaces were manufactured in silicone material that had mechanical properties similar to those of tough foodstuffs. The instrument has such clinical merits, as to favor its use in experimental clinical studies on the biomechanics of prosthetic applications. An electrolarynx which can change intensity as well as frequency simultaneously during conversation was described in [18]. A specialized FSR sensor was used to make possible controlling frequency and intensity simultaneously by applying pressure to the button. This system can be used as one of the rehabilitation methods for laryngectomees. From above-mentioned review of open literature it can be concluded that there are a huge interest for application of FSRs and consequently their custom-made innovative design.

This paper proposes various designs of FSRs on mechanically flexible substrate which can be exposed to a wide range of applied force (up to 65 N). The four types of FSRs were fabricated on the foil (Kapton film), with very low value of resistance in a wide range of applied forces. In-house measurement setup tool has been developed for determining characteristics of these FSRs. Comparison of their performances was performed with reference to resistance vs. applied force curve as well as changing these graphs with increasing the operating temperature which is very important from application point of view.

The article is organized as follows. Section 2 describes design and fabrication procedure of the proposed FSRs as well as measurement setup tool used for characterization of the manufactured force sensing resistors. Discussion of obtained results is presented in Section 3. The concluding remarks are given in Section 4.

2 Experimental

2.1 FSRs design and fabrication

In this paper, four different designs of force sensing resistor were proposed, as can be seen in Fig. 1. First two structures are round and they have different shapes of interdigitated electrodes, while the third structure has square shape active area (Fig. 1c). The fourth structure has 4-zones active area, and just first zone has been used for testing, shown in Fig. 1d.

Table 1: Dimensions of 4 different types of FSRs

	1st type of FSR	2nd type of FSR	3rd type of FSR	4th type of FSR
Active area diameter/surface (mm)	12.7	12.7	24 x 24	18 x 18
Length of structure with terminals (mm)	51.4	51.4	63.4	38.83
Width of interdigitated electrodes (mm)	0.4	0.2	0.4	0.36
Distance between interdigitated electrodes (mm)	0.4	0.5	0.3	0.27

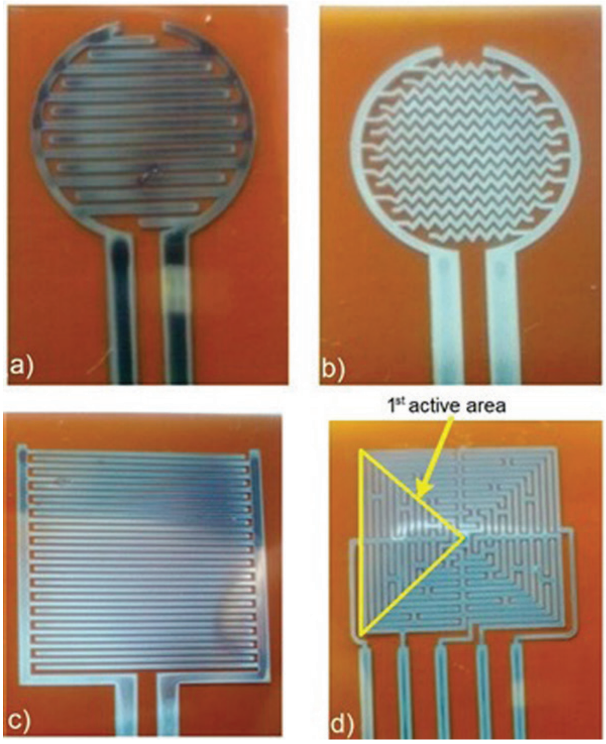

Figure 1: Four different structures after sintering: a) 1st type of FSR, b) 2nd type of FSR, c) 3rd type of FSR and d) 4th type of FSR, respectively

Dimensions of four types of fabricated sensors are shown in Table 1. All FSRs were manufactured by inkjet printing using Dimatix deposition material printer - DMP3000 [19] and RK Control printing proofer - RK K [20].

The first layer of the sensor was fabricated by printing of commercially available SunChemical silver nanoparticle ink with 20 wt% - Jet Silver U5714 [21]. Thickness of polymide film for active area was 75 µm. The resolution of the inkjet process using DMP-3000 printer is mainly governed by the nozzle diameter (approximately the droplet diameter) and the statistical variation of the droplet flight and spreading on the substrate. In case of printing with silver nanoparticle ink the minimum droplet diameter was around 36 µm, and drop spacing was 18 µm (from center to center) obtained by changing the printhead angle. Silver interdigitated electrodes for the first FSR's layer were printed and sintered at 240 °C for 30 min. The second sensor's layer was fabricated by printing of carbon ink using RK K printing proofer on 50 µm GTS polyimide film [22]. Carbon ink has been printed in several layers (three) on GTS film, shown in Fig. 2a. After fabrication both layers have been attached using two component epoxy glue, which has been mounted around the edges of the active area, shown in Fig. 2b. When the two substrates are pressed together, the microscopic protrusions on the FSR ink surface shorten across the interdigitated fingers of the facing surface. At low forces, only the highest protrusions make contact, while at higher forces, there are more and more contact points between the two substrates. The result is that the resistance between the electro conductive segments is inversely proportional to the applied force. The contact wires were mounted using silver paste, for testing purpose, at the ends of silver conductive lines and after finishing these steps, the four types of fabricated FSRs can be seen in Fig. 2c.

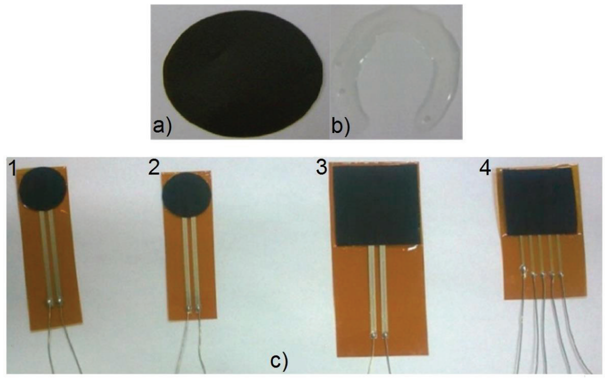

Figure 2: a) Printed carbon ink, b) mounted two component epoxy glue and c) four types of FSR sensors after manufacturing, respectively

2.2 Characterization techniques

The following instruments have been used for materials characterization: (1) for structural characterization - scanning electron microscope (SEM), JOEL JSM 6460 LV scanning microscope with EDS; (2) for mechanical characterization - nanoindentation, Nanoindenter G200, which uses the Berkovich diamond indenter with a face angle of 65.27°.

2.3 Measurement setup

The force sensing resistors testing were performed using an innovative in-house developed measurement setup shown in Fig. 3. It consists of a rigid frame, linear electric actuator with position feedback, spring, actuator sensor holder and reference force sensor. The complete system also includes digital electronic system control and operator control software (user friendly in-house developed software tool, entitled Forcer) shown in Fig. 4, which allows position change and changing of applied force [23]. Resistance and voltage of fabricated sensors were measured using multimeter (shown in Fig. 3b). For the purpose of measurements a voltage source was used (Fig. 3b). Force used for measurements was applied to the fixed part or all over the active part of the sensor.

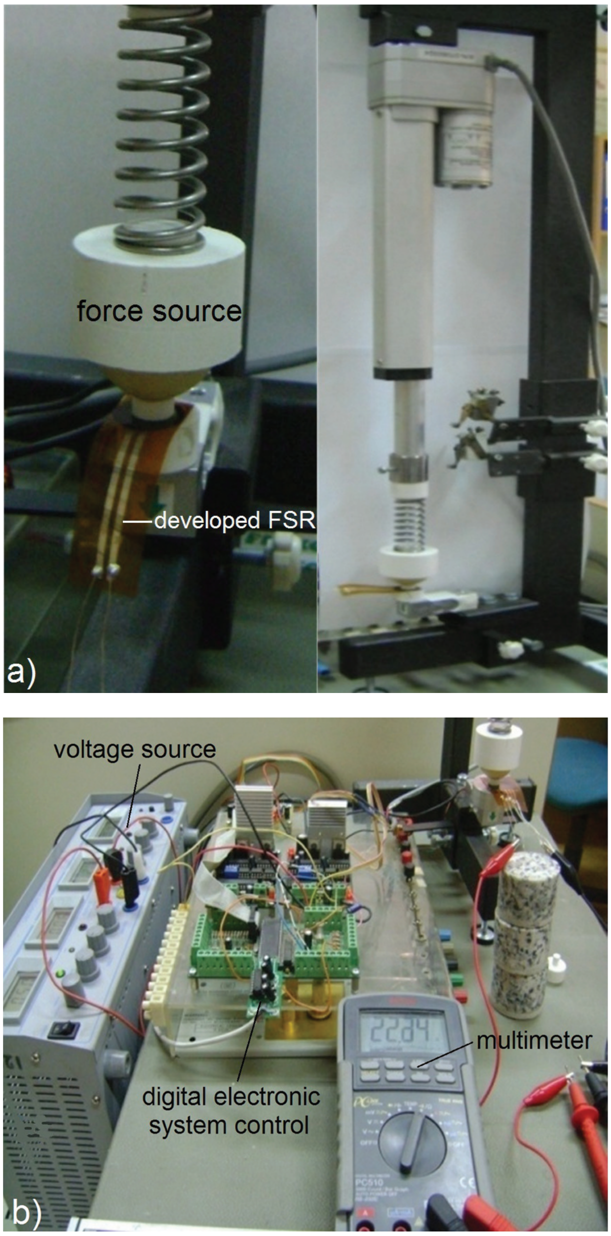

Figure 3: a) Positioning FSR and b) complete measurement setup

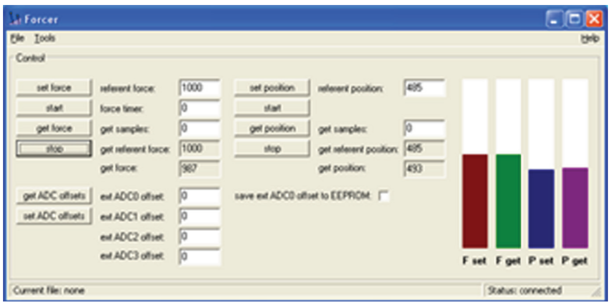

Figure 4: In-house developed software tool for controlling the measurement process.

For resistance as a function of force, measurement setup described at the beginning of this section was used, and for voltage as a function of force, as addition to the setup, a voltage divider circuit which was connected to fabricated FSR, shown in Fig. 5, was used. The measuring resistor, R_M, is chosen to maximize the desired force sensitivity range and to limit current. For resistance as a function of temperature heat source was used to reach the desired temperature and an IR camera was used to monitor temperature variations.

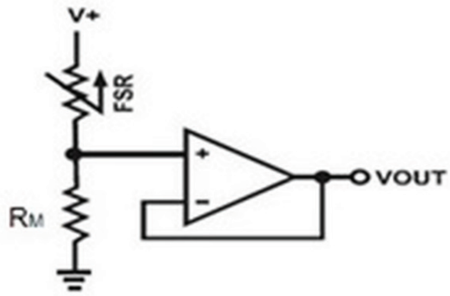

Figure 5: FSR voltage divider circuit

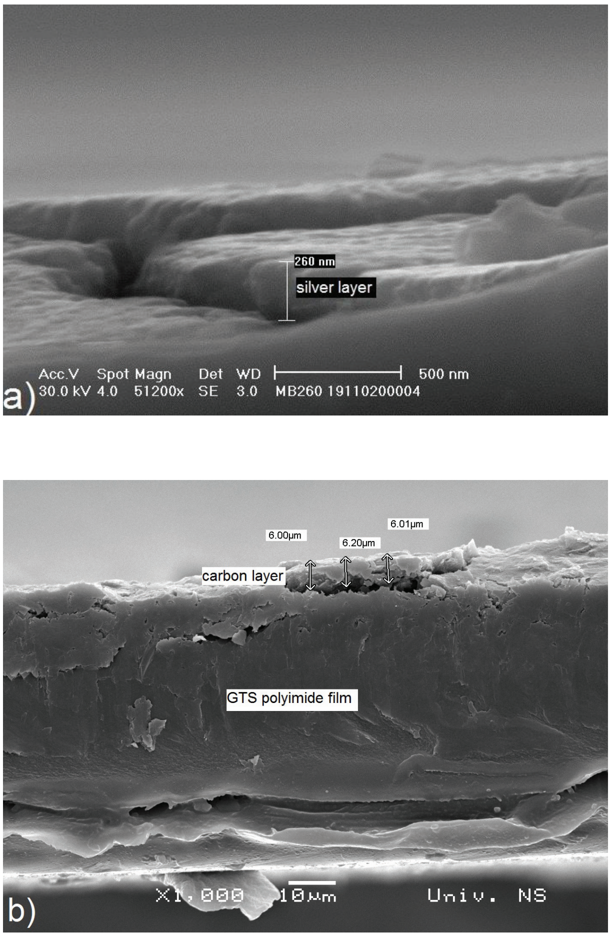

Figure 6: SEM micrographs of a) silver interdigitated electrodes, b) carbon layer

3 Results and discussion

3.1 SEM results

With the aim to determine the exact thickness of silver conductive layer as well as carbon layer, scanning electron microscopy (SEM) was conducted. SEM micrographs are presented in Fig. 6. It can be seen from this figure that thickness of silver layer was around 260 nm, whereas the thickness of carbon layer was around 6 μm.

3.2 Mechanical characterization results

Bearing in mind that FSRs will be exposed to different mechanical stress during the practical application, their mechanical characterization was performed by means of nanoindentation. We used an Agilent Nano indenter G200 to investigate mechanical properties of sintered silver layers as well as carbon layers. Multiple indentation (at least 10 indentations were made) tests provide measurement repeatability for the mechanical properties of analyzed samples/layers. Nanoindentation tests were conducted with a Berkovich diamond indenter, which ensures a precise control over the indentation process. Fig. 7a shows load-displacement curves measured on the silver layer, whereas Fig. 7b presents load-displacement curves measured on the carbon layer.

It can be seen from Fig. 7a that maximum load on silver layer was at 0.35 mN and corresponding maximum depth of penetration was around 240 nm, which confirm that we did not reach the substrate (the thickness of this layer is around 250 nm). Fig. 7b presents load-displacement response for carbon layer for a maximum load of about 1.8 mN and the penetration depth was about 2.25 μm (which is around one third of the thickness of this layer). These force-displacement curves confirm repeatability of obtained results.

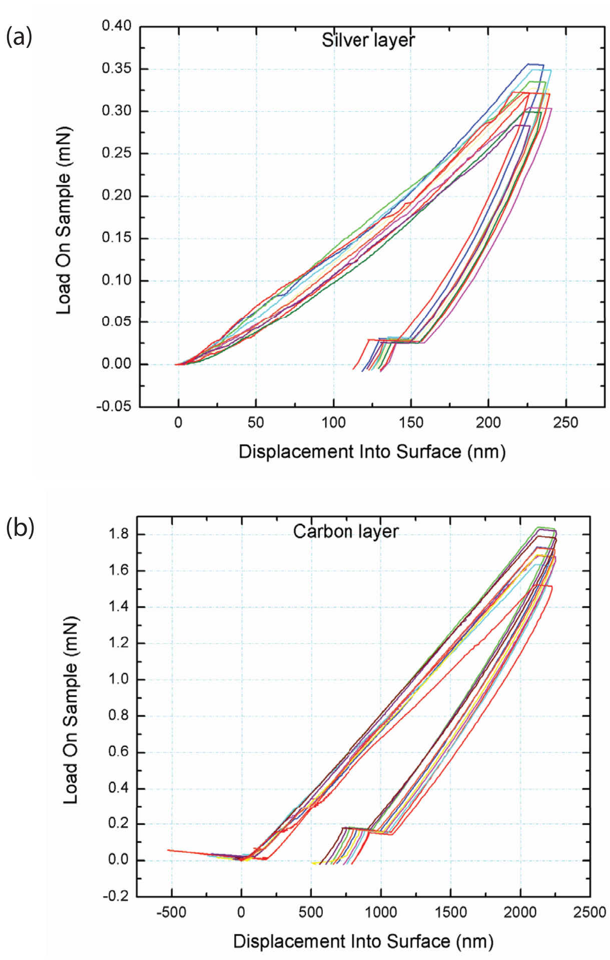

Figure 7: Load-displacement curves for a) silver interdigitated electrodes, b) carbon layer

3.3 Resistance/Voltage vs. force results

A typical FSR's characteristic represents dependence of resistance vs. force, thus we analyzed firstly this behaviour of the proposed sensors. The resistance as a function of force characteristic for four types of FSRs, at room temperature, is depicted in Fig. 8. Three areas of different sensor behaviour can be distinguished. The first area is leftmost area in which the resistance is high and the sensitivity is also very high. This area has nonlinear properties of a dead lash at the beginning of the area characterized by a breaking force that introduces the sensor in the high sensitivity area. The component abruptly switches into the second – the regular area, which is commonly used for sensing. In this area the conductance fairly linearly depends on the applied force (force difference). Finally, when excessive force is applied, the component starts to saturate. The transition to the saturation is not abrupt, but rather gradual [24]. Fig. 8 shows that resistance of sensor decreases

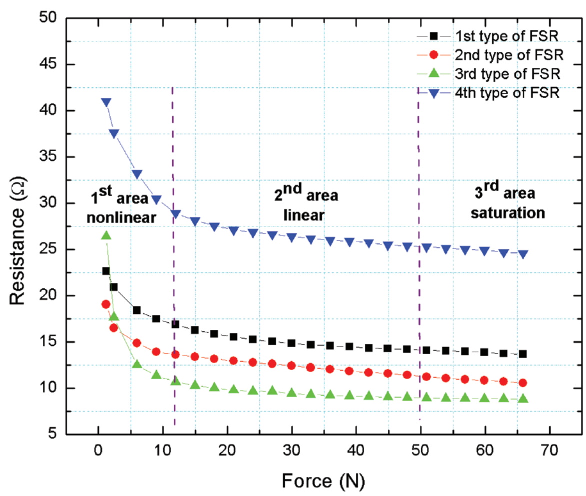

Figure 8: Resistance as a function of force for four types of FSRs

with an increase in force, and it can be observed for all types of analyzed FSRs.

The force range was from 1.19 N to 65.7 N and the same range was used for all four types of FSRs. This force was implemented on FSRs by means of in-house developed system, presented in Fig. 3. In Fig. 8 is visible that the third type of FSR, which has the largest active area, has lowest resistance, 8.81 Ω when applying maximal force, while the fourth type of FSR, with smallest analyzed active area, has resistance of 24.81 Ω when applying the same force. For practical application point of view and connecting with electronic circuits, it is important to have voltage-force characteristics. FSRs are usually configured in voltage divider circuits for simple resistance-to-voltage conversion, as already shown in Fig. 5. Voltage change due to change in force for several values of R_M resistor (depicted in Fig. 5), which allows voltage change in the whole range, is presented in Fig. 9 and 10. Moreover, Fig. 11 depicts voltage as a function of applied force for proposed types of FSRs, for constant values of R_M equal to 18 Ω.

The voltage increases with the increase of applied force, which can be seen using voltage divider equation:

(a)

(b)

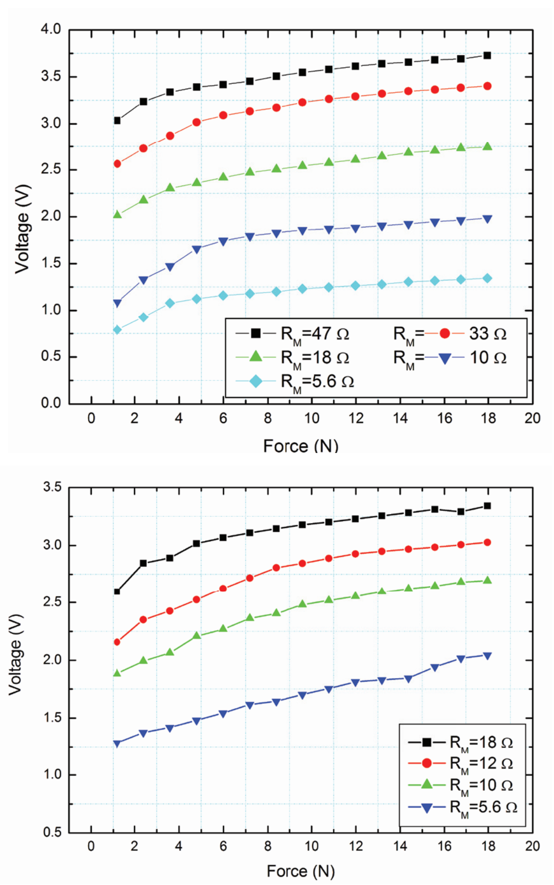

Figure 9: Voltage as a function of force characteristics for: (a) 1st type of FSR, (b) 2nd type of FSR

$$V_{out} = \frac{V_+}{1 + \frac{R_{FSR}}{R_M}} \quad (1)$$

where V_{out} is output voltage, V_+ bias voltage, R_{FSR} resistance of FSR, and R_M measuring resistor. The resistance of FSR decreases with increasing force. Applying that in (1), V_{out} increases with R_{FSR} decrease, which can be seen in Figs 9 - 11. This is valid for all four types of the

(a)

(b)

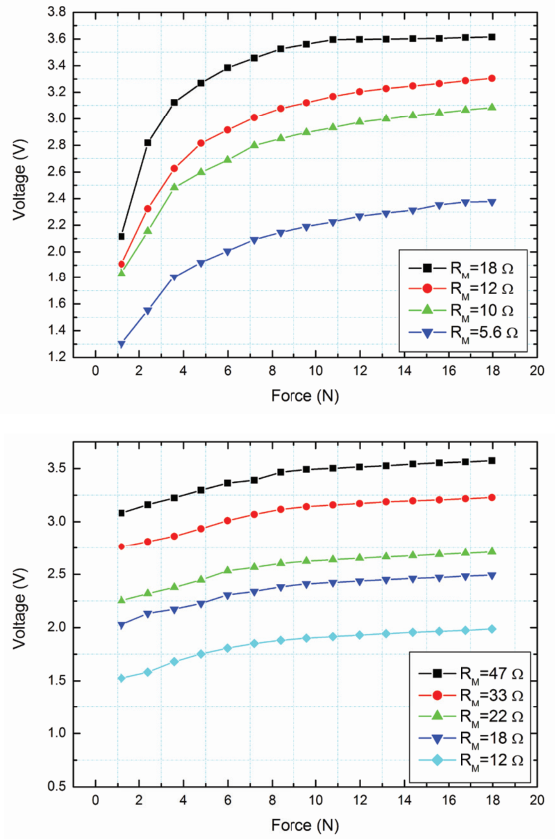

Figure 10: Voltage as a function of force characteristics for: (a) 3rd type of FSR, (b) 4th type of FSR

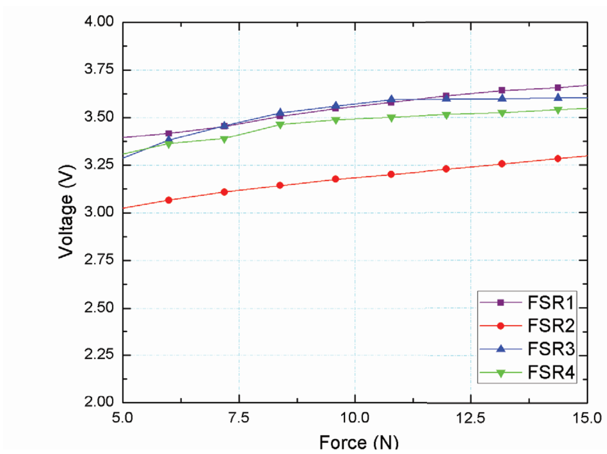

Figure 11: Voltage as a function of force for four types of FSRs and for R_M = 18 Ω in linear sensors' regime

proposed sensors. From Fig. 11, it can be seen that voltage range is from 3 V to 3.5 V, which is very appropriate range for further connection to read-out electronics or displays. Using (1) it can be also calculated which value of R_{FSR} will be obtained for already measured voltage shown in Figs 9 and 10. This will confirm validity of resistance values shown in Fig. 8. R_{FSR} can be calculated from the following equation:

$$R_{FSR} = R_M \left(\frac{V_+}{V_{out}} \right) - R_M \qquad (2)$$

where $V_+ = 5$ V.

In Fig. 11 can be seen that applied force was from 5 N to 15 N, since at larger forces changes in voltage are negligible due to small change of R_{FSR}. Fig. 11 shows that the output of the sensor varies linearly with the force applied. The 2nd type of FSR demonstrated the best linearity, in a wide range of applied forces. This FSR has our novel design and can not be found commercially.

FSRs may also find their application in systems with higher temperature than room temperature. Because of that, we analyzed the behaviour of the proposed FSRs at elevated temperature. Fig. 12 shows that resistance of FSRs increases with an increase in temperature. Temperature was changed in the range from 30 °C to 90 °C, while applied force was constant with value of around 12 N (which belongs to a linear range). This increase of resistance can be explained using following equation for R(T) at room temperature:

$$R(T) = R(T_0)(1 + \alpha_0 \Delta T) \qquad (3)$$

where α_0 is temperature coefficient, $R(T_0)$ is resistance at room temperature, and $\Delta T = T - T_0$ is difference between actual and room temperature. As α_0 for silver is 0.0061 $°C^{-1}$ and for carbon -0.0005 $°C^{-1}$, using (3) it can be seen

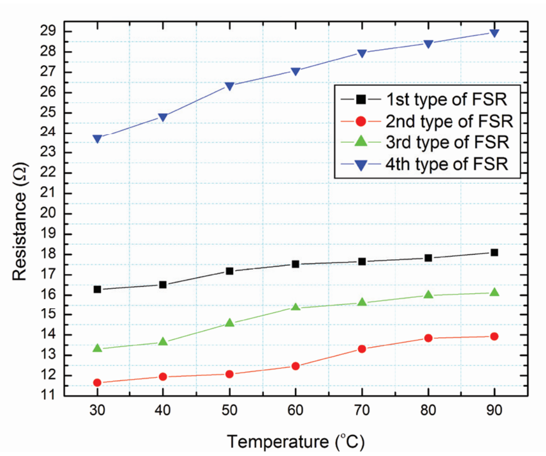

Figure 12: Voltage as a function of force for four types of FSRs and for $R_M = 18\ \Omega$

that with an increase in temperature, value of R(T) also increases. This increase in resistance can be observed for all four types of FSRs (Fig. 12). It can be seen that the smallest variation of resistance with changing temperature demonstrated the first and second types of FSRs which have the lower total active area, comparing with the third and the fourth design of proposed FSRs. In addition to this, α_0 for all four fabricated FSRs has been calculated and results are presented in Table 2.

Table 2: Temperature coefficient α_0 for characterized FSRs

	α_0 ($°C^{-1}$)
1st type of FSR	0.0019
2nd type of FRS	0.0032
3rd type of FSR	0.0035
4th type of FSR	0.0037

The obtained results are directly connected with sensors structure. When pressed or touched, the FSR ink carbon based structures act as a short between the conductive traces from the contact area, resulting in a resistance that depends on the applied force. When the two substrates are pressed together, the microscopic protrusions on the FSR ink surface shorten across the interdigital fingers of the facing surface. At low forces, only the tallest protrusions make contact, while at higher forces, here are more and more contact points between the two substrates. As a consequence, the resistance between the electro conductive lines is inversely proportional to the applied force, as presented in Fig. 8. The voltage is directly proportional with applied force, in accordance with equation (1), and as it is demonstrated in Figs 9-11. Our results revealed that presented cost-effective FSRs are reliable and have a good sensing property for measuring force. The proper design of FSRs, which this paper has proposed (even unconventionally), is very important when dealing with different shape of objects, in order to be able to detect adequately applied force.

4 Conclusion

In this paper four types of flexible FSRs, fabricated in low-cost and easily accessible ink-jet and screen printing technologies, with different design of active area were tested. Each of four FSRs shows that measured resistance of FSR decreases with an increase in applied force, that voltage increases with an increase in force and that resistance increases with an increase in temperature. Measured values of resistance were in the range of 8.81 - 24.81 Ω and voltage was in range from 0.79 V to 3.73 V, while applied force from around

1 N up to maximum of 65 N. Obtained results showed that sensor with largest active area has lowest resistance when applying maximal force, while sensor with smallest active area has largest value of resistance at the same applied force. The novelty of this paper can be summarized as follows: (1) innovative design of second type of FSRs which showed the best linearity and the smallest resistance variation at elevated temperature comparing to other designs which can be usually found off-the-shelf; (2) together with flexibility and thin structure of the sensor this brings a very wide possibilities of sensors applications in many delicate and important fields such as prosthetic medicine, dentistry, rehabilitation, robotics, etc.; (3) comparison of the complete set of performances of four different types of FSRs performed for the first time; (4) presented FSRs can be exposed to a wide range of applied forces up to 65 N; and (5) completely novel in-house developed system for experimental testing of FSRs has been presented.

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6 References

1. T. D' Alessio, "Improving the use of force sensing resistors arrays for the measure of hand grasp", Proceedings of the electrotechnical conference, MELECON '96, vol. 3, pp. 1383-1386, 1996. DOI: 10.1109/MELCON.1996.551205
2. A. A. Gopalai, "Force sensing resistors for monitoring proprioception response in rehabilitation routines", Proceedings of the 12th international conference on intelligent systems design and applications (ISDA), 27-29 November 2012, pp. 941-946. DOI: 10.1109/ISDA.2012.6416665
3. N. K. Rana, "Application of Force Sensing Resistor (FSR) in design of pressure scanning system for plantar pressure measurement", Proceedings of the second international conference on computer and electrical engineering, ICCEE '09, 28-30 December, 2009, vol. 2, pp. 678-685. DOI: 10.1109/ICCEE.2009.234
4. Interlink Electronics, "FSR® Integration Guide", FSR® Force Sensing Resistors®, pp. 11-12.
5. Tekscan, Inc., 307 West First Street, South Boston, "Comparison of interface pressure measurement options", pp. 2. – See more at: http://www.tekscan.com/pdf/Comparison-Pressure-Measurement-Options.pdf
6. IEE International Electronics & Engineering. Specification Sheet for Standard LuSense Sensors of the PS3 Family. Revision 0, March 29, 2001.
7. C. Lebosse, B. Bayle, M. De Mathelin, and P. Renaud, "Nonlinear modeling of low cost force sensors," 2008 IEEE Int. Conf. Robot. Autom., pp. 3437–3442, 2008. DOI: 10.1109/ROBOT.2008.4543736
8. A. S. Sadun, J. Jalani, J.A. Sukor, "Force Sensing Resistor (FSR): A Brief Overview and the Low Cost Sensor for Active Compliance Control", First International Workshop on Pattern Recognition, edited by Xudong Jiang, Guojian Chen, Genci Capi, Chiharu Ishii, Proc. of SPIE Vol. 10011, 2016. DOI: 10.1117/12.2242950
9. M. Y. Saadeh, M B. Trabia, "Identification of a force-sensing resistor for tactile applications", Journal of Intelligent Material Systems and Structures, vol. 0, pp. 1-15, 2012. DOI: 10.1177/1045389X12463462
10. R. S. Hall, G. T. Desmoulin, T. E. Milner, "A technique for conditioning and calibrating force-sensing resistors for repeatable and reliable measurement of compressive force", Journal of Biomechanics, vol. 41, pp. 3492-3495, 2008. DOI: 10.1016/j.jbiomech.2008.09.031
11. D. Giovanelli, E. Farella, "Force Sensing Resistor and Evaluation of Technology for Wearable Body Pressure Sensing", Journal of Sensors, Vol. 2016, Article ID 9391850, 13 pages. DOI:10.1155/2016/9391850
12. M. F. Shaikh, Z. Salcic, K. Wang, "Analysis and Selection of the Force Sensitive Resistors for Gait Characterisation", Proceedings of the 6th International Conference on Automation, Robotics and Applications, Feb 17-19, pp. 370-375, 2015, Queenstown, New Zealand. DOI: 10.1109/ICARA.2015.7081176
13. C. Cho, Y. Ryuh, "Fabrication of flexible tactile force sensors using conductive ink and silicon elastomer", Sensors and Actuators A: Physical, vol. 237, pp. 72-80, 2016. DOI: 10.1016/j.sna.2015.10.051
14. A. Nikonovas, A. J. L. Harrison, S. Hoult, D. Sammut, "The application of force-sensing resistor sensors for measuring forces developed by the human hand" , Proc. of the Institution of Mechanical Engineers, Part H: Journal o Engineering in Medicine, vol. 218, pp. 121-126, 2004. DOI: 10.1243/095441104322984013
15. R. Bin Ambar, B. M. P. Hazwaj, A. M. B. M. Ali, M. S. Bin Ahmad, and M. M. Bin Abdul Jamil, "Multi-sensor arm rehabilitation monitoring device," 2012 Int. Conf. Biomed. Eng. ICoBE 2012, no. February, pp. 424–429, 2012. DOI: 10.1109/ICoBE.2012.6179051

16. B. T. Smith, D.J. Coiro, R. Finson, R.R. Betz, J. McCarthy, "Evaluation of force-sensing resistors for gait event detection to trigger electrical stimulation to improve walking in the child with cerebral palsy", IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol. 10, No. 1, pp. 22-29, 2002. DOI: 10.1109/TNSRE.2002.1021583
17. C. P. Fernandes, P.J. Glantz, S.A. Svensson, A. Bergmark, "A novel sensor for bite force determinations", Dental materials, Vol. 19, Issue 2, pp. 118-126, 2003. DOI: 10.1016/S0109-5641(02)00020-9
18. H. S. Choi, Y.J. Park, S.M. Lee, K.M. Kim, "Functional Characteristics of a New Electrolarynx "Evada" Having a Force Sensing Resistor Sensor", Journal of Voice, Vol. 15, No. 4, pp. 592-599, 2001. DOI: 10.1016/S0892-1997(01)00062-5
19. http://www.fujifilmusa.com
20. http://www.rkprint.co.uk
21. http://www.sunchemical.com
22. http://www.gts-flexible.com
23. L. Nagy, D. Krklješ, K. Babković, "Specific conductance characteristic of force sensing resistor with custom made single-gap conductive contacts", Materials and applications for sensors and transducers II, Vol. 543, pp. 184-187, 2013. DOI: 10.4028/www.scientific.net/KEM.543.184
24. D. Krklješ, L. Nagy, K. Babković, "Evaluation of the possibility of using a different excitation of FSR force sensor", Proceedings of the international symposium on power electronics – Ee2011, Novi Sad, Serbia, October 26-28, 2011, pp. 3. ISBN 978-86-7892-356-2

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