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Flexible Piezoresistive Force Sensor Fabrication Based on PCB Process

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Abstract— Flexible force sensor got a considerable concern in academic research due its importance in an interesting fields like robotics and biomedical that have been widely used in life applications. In this work, step by step method of flexible force sensor fabrication that based on the printed circuit board manufacturing method has been presented. Two different designs of flexible force sensitive resistor have been fabricated using piezoresistive polymeric material called Velostat. The sensors have been evaluated by measuring the resistance using compression system during different loads implementation and comparing the sensitivity with the conventional flexible force sensor in the market. It has been found that the behaviour of the sensor was nonlinear, where the single output design sensor recorded a sensitivity starting with 2153(Ω/N) and reduced to 28.5(Ω/N) while the load has been increased. At the end, the fabricated sensor appeared good flexibility, finishing and ability to match different application shape, furthermore, a good sensitivity which was close to the sensitivity of the commercial flexible force sensor.

Keywords— Flexible force sensor, Velostat, Printed circuit board, Fabrication

I.INTRODUCTION

Modern digital electronics has been widely improved to the extent that the capability of computation become possible to be included into daily objects, especially after the evolution of using flexible, wearable, and imbedded sensors in robotics and biomedical applications.(1)

Tactile sensor is highly needed for the implementation of robotic. The prosperity of robotic intelligent technology and the availability of flexible and wearable tactile sensors paved the way for the next generation of robots, medical devices as well as the human prosthesis technology which became from the hottest topics in academic research. (2)

Pressure sensor that made from stiff material which are widely used are not convenient for flexible or wearable applications, while flexible pressure sensors that has the ability to deals with curvilinear surfaces have been gotten a great concern in fields like of human-machine interfaces, soft robotics, e-skin, medical diagnosis and treatment. Studying the performance of the flexible pressure sensor like sensitivity, resolution, time response, stability and robustness got a great importance with a view to conform those previous emerging applications. (3)

In the fields has been mentioned above, specific measurements can be obtained from specific application human body itself using sensors to get important information specially that in contact within the external environment. To highlight the importance of this academic topic, some scientific research works in biomedical field that using flexible force sensor will be mentioned.

Hudec et al. worked to detect the position of a bedridden patient using smart IOT system based on sixty-four electrically conductive textile pressure sensors to collect the pressure distribution of lying person. This system sends the information to a disc top application and alarm the nursing stuff when it is necessary to change the patient's lying position in order to prevent bedsores (4). Gongfa et al. used a flexible tactile sensor structed from thee layers with prosthetic hand. The upper layer made from indium-tin oxide polyethylene terephthalate to detect pressure positioning; the intermediate layer made from piezoresistive that change its resistance according to the amount applying load, while the third layer represent the electrode which made from conductive material used to collect the signal. This sensor has been embedded within prosthetic hand to provide information about forces of interaction and surface properties at points of contact between hands and objects in order to integrate the artificial sensory perception and haptic feedback in prosthetic hands to restore the grasping function (5). Adam et al. used 16 commercial flexible force sensor elements for designing an insole using as a mobile gait analysis to analyse the gait cycle by measuring determine ground reaction force plus moments corresponding to ankle dorsiflexion/plantarflexion, knee flexion/extension, and knee abduction/adduction for control person group and patient group with stroke. (6). Suresh et al use the flexible pressure sensor to improve the of treatment of chronic venous disorders using graduated compression therapy by implementing five different size low-cost commercial pressure sensors five different size five low-cost commercial pressure sensors on a human-leg-like test apparatus and presents quantitative results on the accuracy and drift behaviour of these sensors in both static and dynamic conditions required for compression therapy. (7)

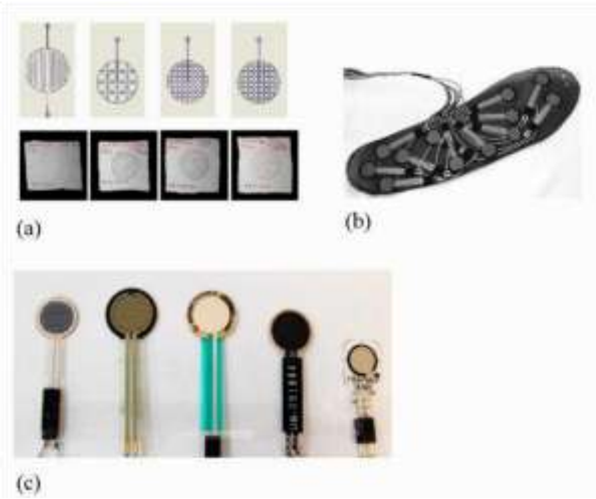

Fig 1. (a) FSR using for detection of patient lying person. (b) FSR using for insole mobile gait analysis. (c) Different commercial FSR

The previous different applications of flexible force sensor show that the sensor need to be design in different shapes and there is no standard commercial sensor can be suitable to cover all these applications. This paper make focus on an easy homemade step by step fabrication of flexible tactile sensor with different shapes.

II.PARTS OF THE SENSOR

The flexible sensor has been constructed from the following:

A. Substrate

Which is the layer that where the electrodes will be fixed so it needs to have a flexible texture to give the sensor the suitable flexibility.

B. Electrodes

That will collect the signal from the sensor. A single sided conductive adhesive copper foil has been attached to the substrate to be used as a sensor electrode. In order to fabricate flexible sensor, two electrodes are needed and organized in a way that allow the current to flow through the pressure sensitive material.

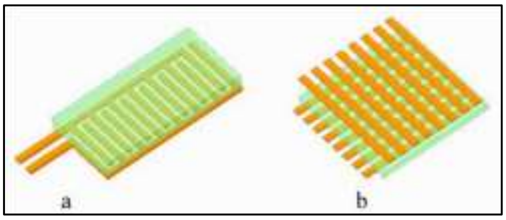

Figure 2. Design of FSR. (a) single output FSR. (b) Matrix FSR

According to the arrangement of the electrodes of the sensor, the pressure senor can be sets in mainly two groups which are single output sensor and multioutput sensor. The single output pressure sensor has interdigitated electrodes arrangement where both electrodes attached on the same side and the same substrate just like the commercial flexible pressure sensors figure (1a). Multioutput sensor has vertical group of array electrodes on one side of the sensor and other horizontal array group of electrodes in such way to get matrix sensor figure (1 b).

C. Sensing material

That form the core of the sensor. This layer represents the sensing material that has the ability to change its physical properties according to the applying load. According to the type of material's property that reacts to the mechanical load, sensors can be mainly classified to three groups which are piezoresistive sensors, capacitive sensors, and piezoelectric sensors. The piezoresistive sensor depends on the phenomena of resistance changing of the material during mechanical deformation by force. The capacitive sensor depends on the gap between two conductive plate that separated by dielectric materials where this gap affected by pressure. The piezoelectric sensor depends on the piezoelectric effect of the material which convert the mechanical energy to electrical energy. I this work, Velostat which is a type of piezoresistive material, has been chosen as a sensitive material for the fabricated sensor.

III.METHODOLOGY

The chosen fabrication method has been highly based on the printed circuit bord (PCB) manufacturing process. The fabrication process of flexible sensor based on PCB can be achieved in a variety of ways and there are a number of variants. Regardless of the variations, the major stages in the manufacturing process can be as follow. In order to cover the importance and the simplicity of this method, the step by step of two different types of sensors, which are a single output flexible force sensor that has been designed to match the shape of 3D printed prosthetic hand, and a multioutput matrix sensor have been described in the fabrication process section.

A. Fabrication Materials

The materials that have been used for the fabrication are:

OHP thermal transfer printer sheets. This flexible plastic sheet has been used as a substrate for the sensor. It can be withstood a temperature up to 150oC without melting.

- Adhesive Cupper foil. This foil will be attached to the flexible plastic substrate to form the electrodes of the flexible sensor. Photosensitive film. This film consisted of a thin substrate that carry a light sensitive layer. This film has been used to laminate the copper foil for further processing.
- Hot laminating machine. This machine has been used to get rid of the air bubble during the lamination of the cupper foil by the photosensitive film.
- UV light box. This is a box consists UV lumps used to transfer the shape of the printed design of the electrodes to the laminated cupper foil.
- Sodium carbonate monohydrate which has been used as a developer solution.
- Ferric chloride which has been used as a copper etching solution.

B. Fabrication Process

1. Software design.

This step based on the previous for the application that the force sensor will be used for. It includes the software design of the shape of the electrode of the sensor with specific accurate dimensions in order to match the shape and the dimensions of the area that wanted to be covered by the sensor. Figure 3a shows the electrode design of multioutput force sensor that will be fabricated as a separated matrix flexible force sensor. Figure **3b** shows the electrode design of two single output sensor that has been used be embedded within the palm of 3D prosthetic hand while **figure 3c** represent different sizes of electrode design of the sensors that will be used for the four fingers of the prosthetic hand. Lines for the scaling of the figure has been added with each design for comparing with the printed sheet.

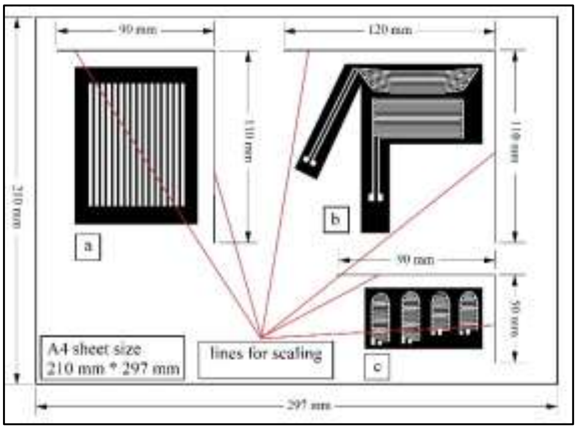

Figure 3. Software design of different FSR

2. Printing The Design

3. Copper Lamination.

In this step, the copper foil needs to be attached carefully with the flexible substrate to ensure a clear surface for the lamination as shown in figure 5(a). After that, the copper has been laminated with a thin layer of a photosensitive film using hot laminating machine to ensure better attachment as shown in figure 5(b).

4. Exposing process.

In this step the semitransparent printed film has been aligned with the laminated cupper and exposed them with UV light using the UV box. The exposed area of the lamination will be hardened by the UV light while the area that are lying under the printed area stay unexposed by the UV. Figure 5(c) and (d) shows the laminated film during and after exposing.

5. Developing process

In this step, the exposed film has been immersed in the developing solution with shaking in order to dissolve the unexposed area of the lamination while the exposed area still be masked as shown in Figure 5(e)

6. Etching process

In this step, the developed film has been immersed in the etching solution with shaking in order to remove the un masking cupper area. The etching solution has been prepared by dissolving about 50 g the ferric chloride in 100 ml of water to get 50% etching solution as shown in Figure 5(g) and (h)

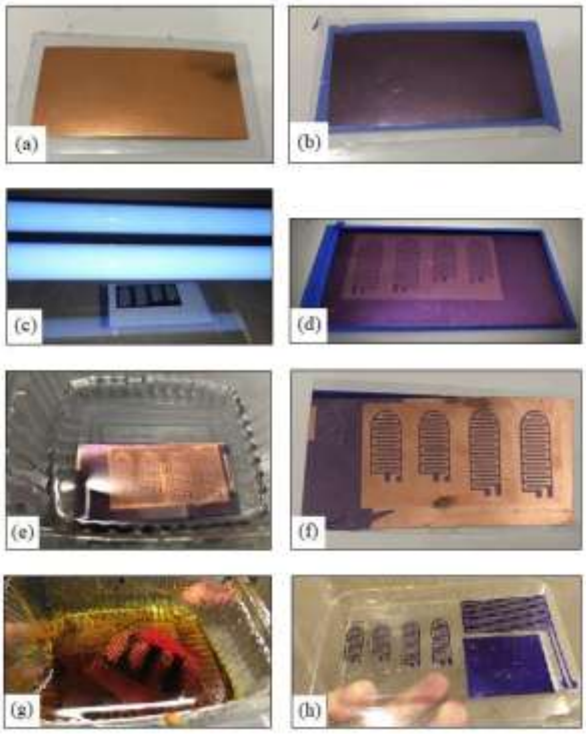

Fig 5. (a) Unlaminated copper. (b) Laminated copper. (c) Laminated copper under UV exposure. (d) Laminated copper after exposing and design transformation. (e) Exposed film during development. (f) Exposed film after developing. (g) Developed film during etching. (h) Developed film after etching

C. Evaluation

A compression system test in figure 6 has been used to evaluate the sensitivity of the sensors. This system using stepper motor using to drive a rotatable bolt to apply specific load as well as four scale sensors with their digital screen to read the applying load during the test. A normal load with specific value has been applying normally to the sensor that has been placed on the compression bench.

In order to measure the resistance of the sensor during the loading phase, the sensor has been connected as in figure 6 and an arduino has been used to calculate the resistance according to the equation:

$$R_2 = \frac{R_1}{\left(\frac{V_{in}}{V_{out}}\right) - 1} \qquad (1)$$

Where R_1 is a known resistance and R_2 is the FSR resistance. As long as the resistance of the FSR has been changed during the loading phase, V_{out} will be changed also. An arduino has been chosen to measure the V_{out} due to its ability to send the measurement to computer as well as it can take many measurements in short time. The matrix sensor that has been designed having 16*16 sensing elements, so it is important to do complete the measurement in short time to prevent creep that may change the reading of the Velostat.

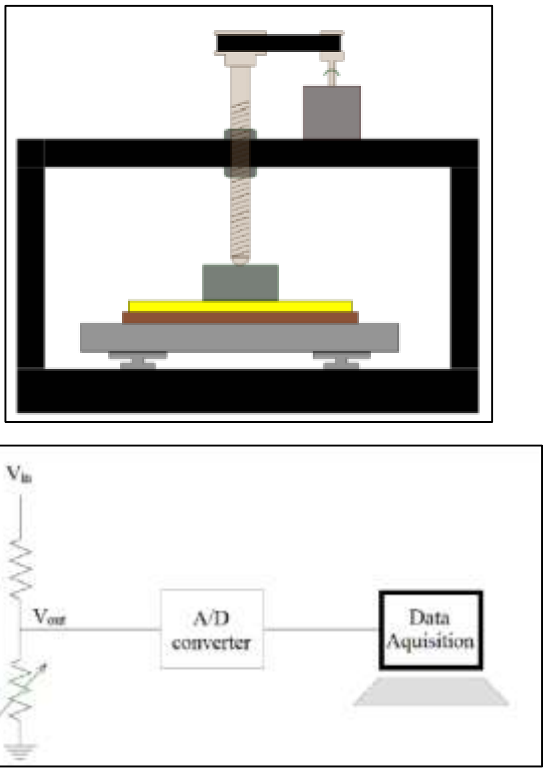

Figure 6. compression testing system

IV.RESULTS AND DISCUSSION

The figure 7 shows the sensor final result of the flexible sensor fabrication and the prosthetic hand imbedded sensor. The final products of the sensor have been characterized a good flexibility due to the good flexibility of the substrate and the Velostat materials, as well as an acceptable fishing. The Finishing the flexible sensor has been better that the imbedded sensor due to the irregularity of the prosthetic hand shape which made the attachment of the adhesive copper foil without folding and air bubble not easy matter.

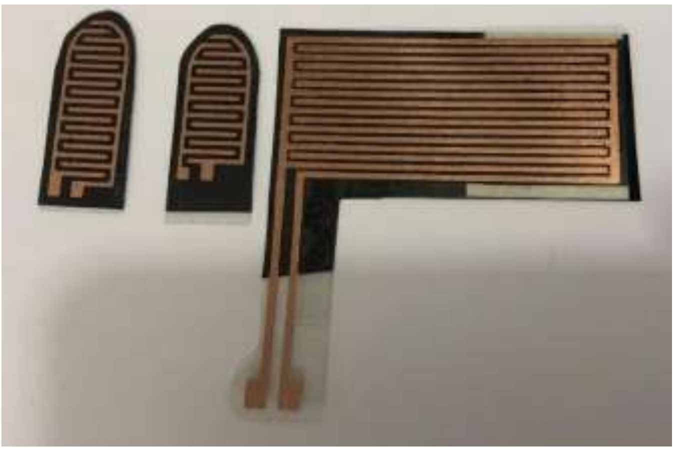

Fig 7. Fabricated flexible force sensor

The sensors response and sensitivity have been evaluated by applying ten different values of load starting from 0.98 N up to 9.8 N with an increment of 0.98 N. Figure 8 shows the response of both single output sensor and the matrix sensor. As shown in figure 8(a) the resistivity of the single output sensor has been changed from (3140 Ω) for an applying load of 0.98 N to (197 Ω) for an applying load of 9.8 N, while the resistivity of the matrix sensor has been changed from (865 Ω) for an applying load of 0.98 N to (95 Ω) for an applying load of 9.8 N. Both sensors have shown nonlinear behaviour during the test due to the nonlinearity of Velostat response for the compression load. To evaluate the response of the sensor, the sensitivity of the single output sensor has been calculated as a change in the resistance of the sensor regarding to the change of the applying load as shown in the figure 9. The maximum sensitivity that has been recorded was 2153(Ω/N). The sensitivity has been decreased as the load increased, where the minimum has been recorded for the range of load between (8.82 N and 9.8 N). This behaviour seems to be close to the behaviour of the conventional flexible force sensor.

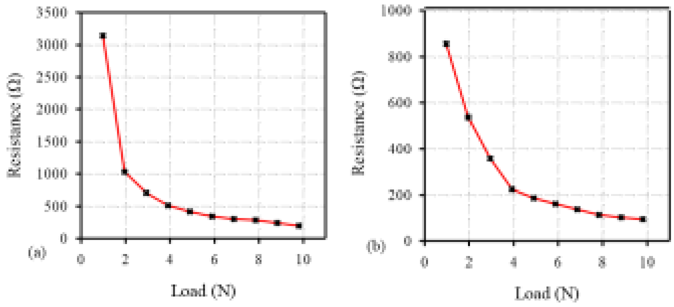

Fig 8. a) the response of the single output sensor for different loads value. (b) the response of the matrix sensor for different loads value.

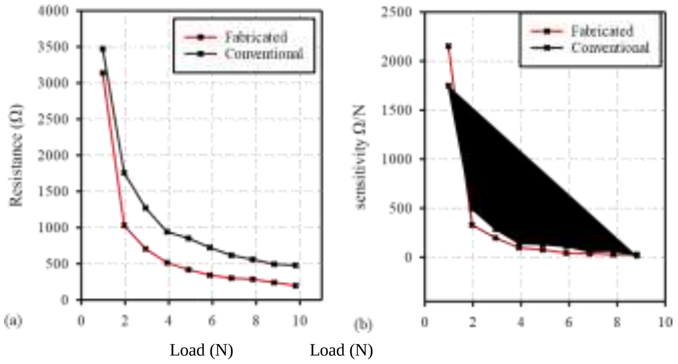

Figure 9 (a) Fabricated FSR response vs commercial FSR. (b) Fabricated FSR sensitivity vs commercial FSR.

V. Conclusion

In this work, a step-by-step flexible as well as imbedded force piezoresistive sensor fabrication method has been presented with all material needed. The final fabricated sensors with different design have shown a good flexibility as well a good finishing. All the sensing material as well as the material of the electrode that has been used in the fabrication of the sensor have an excellent flexibility, thus the flexibility of the sensor has been determined by the flexibility of the substrate that has been used for the electrode attachment. The method of fabrication showed great advantages through its ability to fabricate sensors suitable to cover object with even irregular shape as well as the ability to imbed the sensor for some application which use material not interact with the developing and etching liquids that has been used with the fabrication process. The performance of the fabricated sensor seems to be near from that the conventional piezoresistive flexible force sensor in the market.

VI. References

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