Electrical Resistance Profiling of Bend Sensors adopted to Measure Spatial Arrangment of the Human Body

Giovanni Saggio
Dept. of Electronic Engineering
University of Tor Vergata
Rome, Italy
saggio@uniroma2.it

***Abstract*— Here we report some techniques we adopted to electrically characterize some commercially available bend sensors, in terms of their resistance variations when curved or angular shaped. This study has the aim of a correct exploitation of the bend sensors in order to adopt them for proper measures of the static postures and kinematics of the total human body, in regards for both the trunk and the limbs.**

I. Introduction

Flexible sensors can find many useful applications detecting vibrations, contacts / impacts [1], air / liquid flows, pressures / compressions [2] and, in general, displacements / motions [3]. So they are utilized in the fields of robotic, fitness, music, assistive technology, gaming, etc. But we want here point out the adoption of such sensors for bio-metric purposes. In fact the flex (or bend) sensors, thanks to their electrical resistance variation when flexed, if placed on a moving joint or on a curving/flexing part of a human body, furnish a measure of the movements or placements of a subject. This behavior leads to the advantageous possibility of a continuous monitor of a patient's static and dynamic postures, during his/her motor rehabilitation period [4], or of a supervision of an athlete during his/her sport training. But to obtain satisfactory results it is mandatory a correct exploitation of the bend sensor's properties in terms of its electrical behavior with respect to mechanical non-permanent deformations it can be subjected.

II. Materials

A bend sensor is commonly a passive resistive device typically fabricated by laying a strip of resistive ink on a thin flexible plastic substrate, in lengths between 1" and 5". This sensor, when in laid flat, is characterized by an intrinsic electrical resistance, which increases with sensor's deflection. The bend sensor is not prone to degradation through mechanical contacts, so it is easily applicable in strictly contact with human joints, or other curving/flexing part of the body. The sensor presents a long application life since really few systems breakdown can be due to mechanical failures.

For this work we dealt with commercially available bend sensors distributed by Flexpoint (www.flexpoint.com) and Images (www.imagesco.com) companies. In particular we investigated sensors of different sizes and with none or polyester or polymide overlaminate.

Our purpose was to investigate the electrical resistance's changes when the sensors are subjected to mechanical stresses of two different main typologies: (*A*) bend around a pin with fixed radius of curvature and (*B*) flexure around circles with different radii of curvature. The first case is to mimic movements of elbow, knee, ankle, and finger joints, while the second one is to reproduce movements of spine, shoulder, abdomen, chest and neck.

A. Fixed radius pin

In order to characterize the electrical resistance variation of the sensor vs. its angular degree of bending, we realized a home-made set-up. It consists of hinges, stepper motors with their power supplies, anti-vibration supports, and multimeters.

The hinge is made of a knuckle through which a central circular pin is passed, and two notched leafs extend laterally from the knuckle (see Fig. 1).

Figure 1. Hinges of different sizes

One of the leaf is fixed with the pin, so capable to revolve together it, while the other one is maintained fixed. A stepper motor, with its central axis jointed with the pin, can rotate the revolving leaf, so simulating the movements of a human joint (see Fig. 2). The movements of the stepper motor, the voltage values furnished by the power supplies and the electrical resistance values measured by the multimeters, are all managed by home-made LabView routines.

A first version of the home-made set-up is based upon a single hinge moved by one stepper motor [5]. We designed and realized several hinges, in turn utilized, differing from the radius of the central pin, so to simulate different kind of human joints since, for instance, the dimension of an elbow is, of course, different from that of a knee.

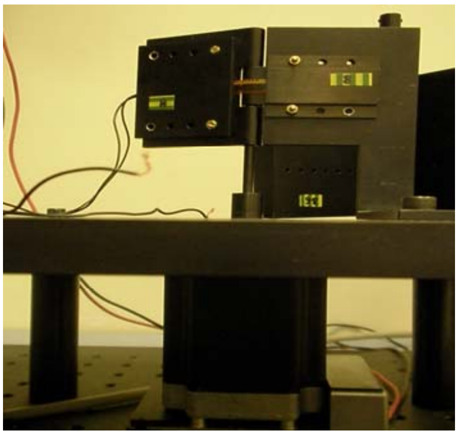

Figure 2. Set-up with fixed radius pin

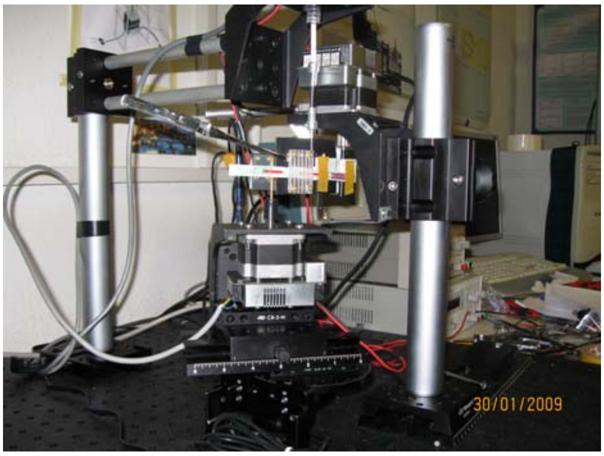

Figure 3. Set-up with three hinges to simulate all finger movements.

A second version of the set-up realizes a manifold system to simulate the movements of an entire finger, with its three joints. It is made of three cross-related hinges, mimicking a multiple pin hinges layout, so that the movements of one leaf of one hinge is capable to translate the complete arrangement of the other two hinges together with their stepper motors (see Fig. 3). It occurs exactly as the real finger, In fact, for instance when the joint, between metacarpal and proximal phalange, bends, the movement of the proximal phalange translates the position of the other two joints of the same finger together with intermediate and distal phalanges.

B. *Variable radius circles*

The two previously described versions of the set-up allow the sensor's characterization, in a sense of simulating its behavior, in terms of changes of its electrical resistance with bending, when lays on a human joint with fixed radius of curvature, as it is for elbow, knee, ankle, and finger joints. But the same set-up is not useful to simulate what happens when the bend sensor lays on a segment of the human body which change its curvature when flexes, as it is for spine, shoulder, abdomen, chest and neck. In fact considering, for instance, a very short segment of the spine, it can be assumed that it modifies its curvature with bending, as it was laying on a ideal circle which varies its radius according to the movement of the spine.

So, we designed and realized another ad-hoc set-up which simulates the bend sensor's movements when forms circular arcs of different radii when submitted to flexion. This set-up consists of a metallic straight rail on which there are two terminals, one of which capable to translate with respect to the other maintained fixed. The sensor is placed between these terminals in a way that when the first terminal is moved, by a controlled stepper motor, towards the second, the sensor forms a sort of circular arc only relative to its electrical sensible part (the black central strip of Fig. 4).

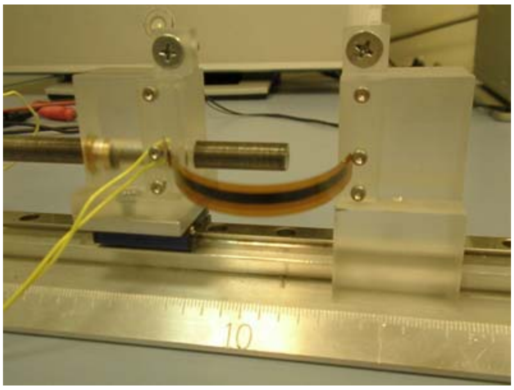

Figure 4. Set-up to investigate the variable radius circles arrangment

III. METHODS

With the "fixed radius pin" set-up, we investigated the electrical features of bend sensors distributed by Flexpoint and Images companies. The characterization was made for 2, 3 and 4.5 inches long sensors with none or polyester or polymide overlaminate, and for an original array of sensors, three on a unique substrate, that we designed for the Flexpoint company. This array, made of three sensors laying on a unique substrate, can measure the three possible flex-extension movements of the three joints of the same finger, (see Fig. 5).

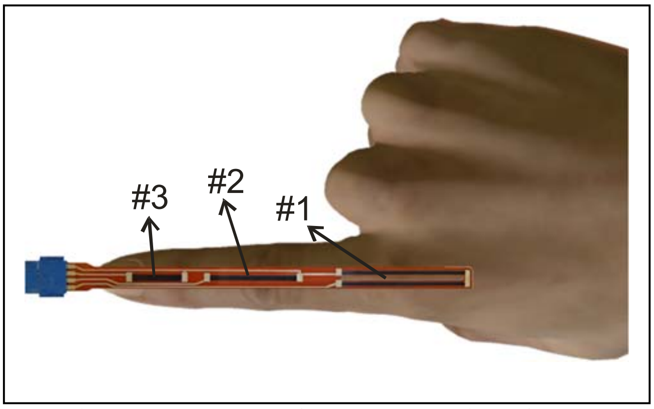

Figure 5. A sensor array: three sensors on a unique substrate

We paid attention also to the bipolar sensing characteristics of the sensors, i.e. their possibility to measures deflection in two opposing directions yielding different changes in electrical resistance values. To this aim let's define as *outward/inward* a flexure of the sensor with its sensible part in extrados/intrados position (i.e. as the outside/inside surface of the curved sensor).

Since the maximum angle of flexion for a finger joint is 120° (in particular for the joint between metacarpal and proximal phalange), all *outward* measurements were performed from 0° (flat position for the sensor) to 120°, with a step of 10°, iterating 10 times, with 10 acquisitions of the resistance values for every step. The same procedure was for the *inward* measurements but ranging from 0° to -120°.

IV. Results and Discussion

The characterizations of the sensors for *outward* bending resulted in comparable results for sensors from the same manufacturer but different in length. As a consequence, the choice of 2, 3, or 4.5 inches of the sensor can be done only on the basis of the dimension of the joint to be measured.

Here we report the measured characteristic of one bend sensor as an example, and in particular the Flexpoint 2 inches long sensor, outward bent from 0° to 120°, stepped 10°, around a 0.5cm radius pin. The measure was repeated 10 times for each step, and the bending between 0°÷120° was repeated 10 times. The results as reported in Fig. 6. The very low standard deviation (drawn superimposed in the figure to each 10° step) and a resistance value which varies from the order of 11kΩ (sensor in flat position), to the order of 165kΩ (sensor 120° bent), implies that this sensor can be successfully adopted to measure the bending of a human joint with an accuracy of the order of the arcdegree.

This is of clear interest since the usual process of measuring the range of motion (ROM) of a patient's hand by a skilled therapist is only repeatable to within 5° if the same physical therapist with a mechanical goniometer performs the measurements [6]. On the contrary, with the adoption of the bend sensors it is possible to monitor the patient's ROM without any assistance of skilled personnel and with a greater accurancy.

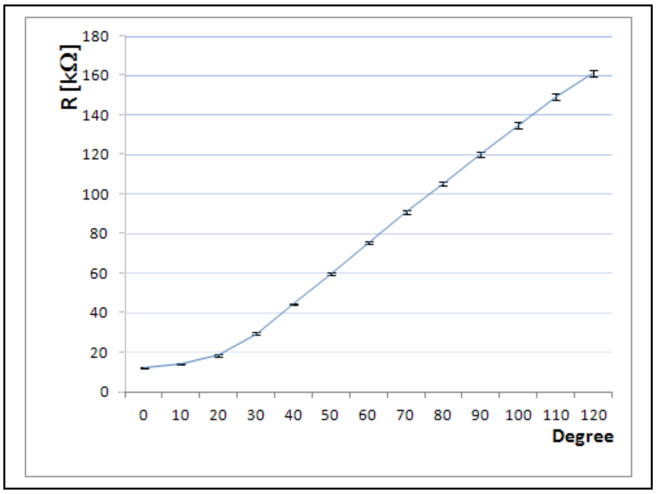

Figure 6. Flexpoint 2" sensor. *Outward* measures

With respect to this result, the measures we performed on the sensors by Image company, demonstrated a slightly worst effect in terms of standard deviation, and the total excursion value of resistance, for a 0°÷120° bending range, was "limited" between 3.5÷8.0kΩ. So their performances are not comparable for outward bending.

Otherwise the case of *inward* bending. In fact the Flexpoint sensors do not present a unique trend in resistance's variation, since relative maximum and minimum values are within 0° and minus 120° acrdegree, and also a not so negligible standard deviation is remarkable (see Fig. 7). So they cannot be succesfully adopted for inward measures. Differing from that, the Image sensors demonstrated a resistance monotonic decrease behavior, as reported in Fig. 8 and, even if their electrical resistance excursion is not so relevant, being "only" in the 13.2÷9.8kΩ range, they can be successfully applied to measure, for instance, the flexion of the antecubital fossa of the elbow or the posterior section of the knee.

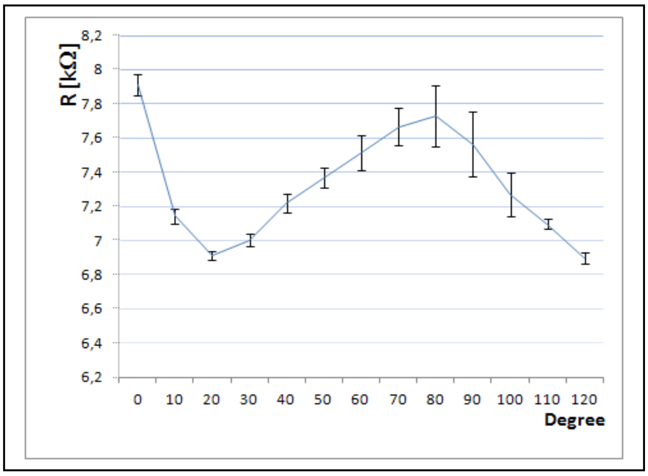

Figure 7. Flexpoint 2" sensor. *Inward* measures

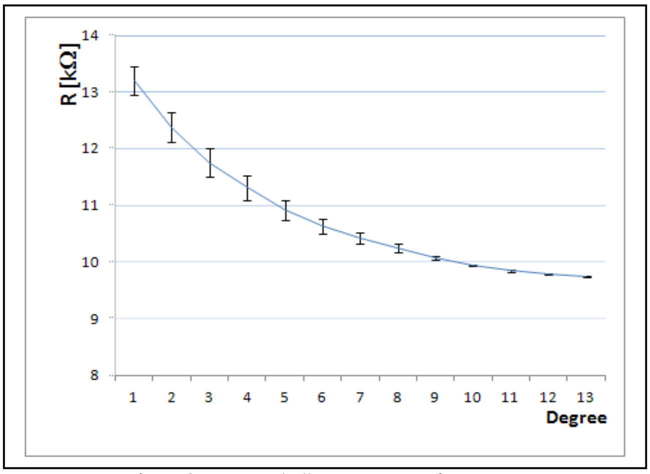

Figure 8. Image 4.5" sensor. *Inward* measures

With the set-up with three hinges (see Fig. 3), we characterized the electrical behavior of an array of three sensors made on the same substrate (see Fig. 5). Three sensors on the same substrate guarantee none misalignments between sensors and the relative joints they are asked to monitor, and avoid a number of wires to be sewn on top of the glove. But the array was design also with the prevision of realizing a unique substrate capable to lodge all the sensors for a whole hand, to obtain a compact structure and with all the wires connected to only one border of the sensor's substrate. So, our question was if a unique substrate could influence the electrical behavior of the sensors. The answer can be obtained analyzing the graph reported in Fig. 9. There are represented the results of complete 0°÷90° sweep, stepped 10°, of the sensor #1 (the one nearest to the dorsal part of the hand), measured every 10° of bending of the sensor #3 (the one nearest to the fingernail). Again the results are comparable to those previously recorded for one sensor alone, but a very little shift of the resistance value must be taken into account for higher bending degree.

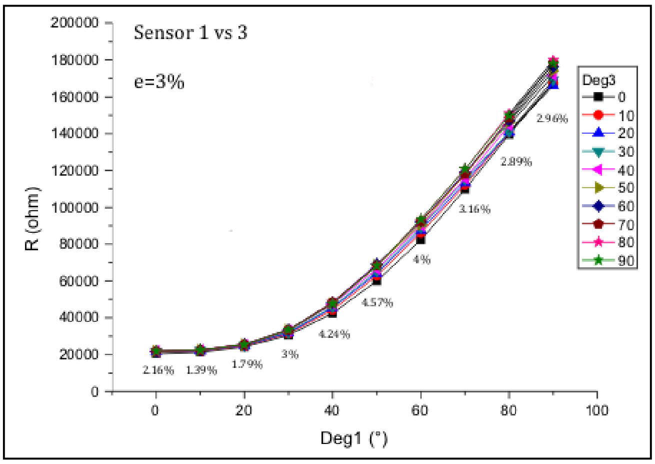

Figure 9. Every 10° of bending angle for the sensor #3, a complete sweep between 0° and 90° is made for the sensor #1

With the "variable radius circle" set-up, we investigated the electrical features of the Flexpoint bend sensors already described, but 1 and 2 inches long, since with a wider length our hypothesis of circular arcs was not realistic. The results are reported in Fig. 10. It shows a monotonic decrease function lowering the distance between the sensor's terminals. In particular the x-axes reports that distance varying between 1 and 11mm, with corresponding values of the radius of curvature of the sensor respectively of 2.5 and 3.5cm. This interesting result demonstrates that those sensors can find successful applications in measuring the parts of the body which vary their curvature when bent.

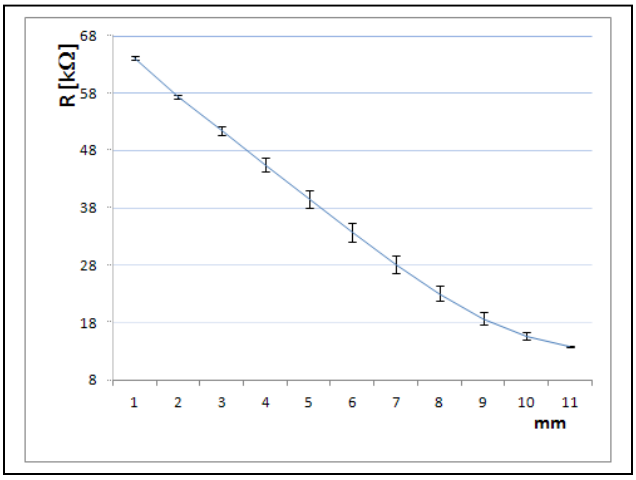

Figure 10. Inward characteristic for 2" lenght Flexpoint sensor

V. Conclusions

We reported complete characterizations of bend sensors in terms of their electrical variations when submitted to bend procedures, intended as outward-inward flex-extension motion around pivots of fixed or variable radii. The results are helpful to exploit in the best way the sensor electrical characteristic so to obtain with them a correct measure of the human postures and kinematics for bio-metric purposes.

References

[1] R. Ponticelli, P. G. de Santos, "Full perimeter obstacle contact sensor based on flex sensors," Sensors and Actuators A 147 (2008) 441–448

[2] W. Peng, D. Tianhuai, X. Feng, "A novel flexible sensor for compression stress relaxation," Second IEEE International Conference On Sensors, 22-24 Oct. 2003, 265 - 268 Vol.1

[3] K. Kure, T. Kanda, K. Suzumori, S. Wakimoto, "Flexible displacement sensor using injected conductive paste," Sensors and Actuators A 143 (2008) 272–278

[4] G. Orengo, L. Giovannini, G. Latessa, G. Saggio, F. Giannini, "Characterization of piezoresistive sensors for goniometric glove in hand prostheses," Wireless Vitae09, Aalborg (Denmark), 17-20 May, 2009 – pp. 684-687

[5] G. Saggio, P. Bisegna, G. Latessa, S. Bocchetti, "Mechanical modeling of bend sensors exploited to measure human joint movements," 1th IEEE International WoWMoM Workshop on Interdisciplinary Research on E-Health Services and Systems, Kos (Greece) June 2009

[6] T.G. Zimmerman, J. Lanier, C. Blanchard, S. Bryson, Y. Harvill "A hand gesture interface device". In Proceedings of the SIGCHI/GI conference on human factors in computing systems and graphics interface, pages 189–192. ACM Press, 1987