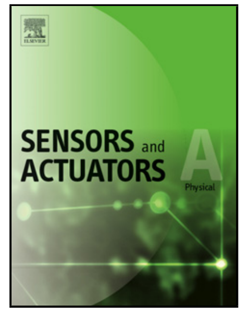
Accepted Manuscript



Title: Flex sensor characterization against shape and curvature changes

Authors: Giovanni Saggio, Giancarlo Orengo

PII:	S0924-4247(17)30162-0
DOI:	https://doi.org/10.1016/j.sna.2018.02.035
Reference:	SNA 10657

To appear in: *Sensors and Actuators A*

Received date:	18-2-2017
Revised date:	21-2-2018
Accepted date:	23-2-2018

Please cite this article as: Saggio G, Orengo G, Flex sensor characterization against shape and curvature changes, *Sensors and Actuators: A Physical* (2010), https://doi.org/10.1016/j.sna.2018.02.035

Flex sensor characterization against shape and curvature changes

Giovanni Saggio[1,2], Giancarlo Orengo[1,2]

[1] Department of Electronics Engineering, Tor Vergata University, Via Politecnico 1, 00139, Rome, Italy
[2] Health Involved Technical Engineering Group (HITEG), www.hiteg.uniroma2.it

Correspondence should be addressed to Giancarlo Orengo, orengo@ing.uniroma2.it.

RESEARCH HIGHLIGHTS

- Sensor device shaping to improve linearity and sensitivity
- Sensor characterization against curvature radius
- Inverse model of the sensor response to draw the bending parameters in real time
- Model calibration to fit measurement on different joint and even different devices

ABSTRACT

Resistive flex sensors were increasingly used in different areas for their interesting property to change their resistance when bent. In particular, they can be applied to human segment in biomedical devices to register static and dynamic postures. In spite of their interesting properties, such as robustness, low price and long life, they often demonstrate non-linear response and lower sensitivity at small bending angles. This paper provides investigation to improve flex sensors linearity and sensitivity to measure body joint angles with better accuracy. To this aim, an empirical model of the sheet (or surface) resistance of the active layer, to simulate its behavior against the layer shape and size as well as the bending angle, was provided, to investigate whether changes of the standard rectangular shape can improve sensitivity and linearity. In addition, to date commercial flex sensors have been characterized only against the bending angle with a radius of curvature smaller than the device length, so limiting the application to small joints such as finger or knee. In order to extend the flex sensor applications, for instance, to measure the trunk posture in back disease and rehabilitation monitoring, the sensor response against a radius of curvature greater than the sensor length was analyzed. Finally, a new modeling technique, based on the inverse model of the sensor characteristic, to enable fast measurements of the bending angle or the radius of curvature from sensor response also in real time, and fast calibration procedures, fitting the same model to measurements with different joint size and even device, were developed.

Keywords: flex sensors; wearable sensors; modeling; calibration; posture recognition; motion capture.

1 Introduction

In order to measure human body posture and kinematics, it is convenient to adopt sensors that can measure bending angles with good precision despite a low cost. The availability of new technologies in the field of flex sensors enables to improve measurement sensibility and accuracy, the fundamental topics to understand, as in deep as possible, the human locomotion control and the motion-neuronal activity. Flex sensors are used as electronic goniometers in biomedical devices, in particular when applied onto wearable socks around human joints, for rotation assessment of body segments in human posture recognition [1-6]. Even though the device size can be practically fitted to any type of joints, the sensor behavior must be characterized in a different way, according to the joint size (small or big) compared to the sensor length. In fact, in case it is small, the sensor is bent only in the central region, where its resistivity increases. On the other hand, in case it is big, the sheet resistance of the active layer increases uniformly along its length, since the sensor strip is subject to a uniform radius of curvature. This paper provides helpful characterizations in both cases.

The sensor strips applied to measure the bend angles of human joints with small radius of curvature, such as finger, knee and elbow, are bent around their half length, and only this region accounts for the resistance increase. In this case, sensors can be characterized on a mobile hinge with a constant radius of curvature, as it has been done to date, with the typical range of movement (ROM) of each application, such as 90° for finger [7] or 120° for knee [8].

On the other hand, when the radius of curvature is longer than the sensor length, it can be assumed that all the sensor strip is bent with a uniform time-varying radius of curvature. For example, this could be the case when flex sensors are applied on garments to register the trunk posture (ROM=100° [9]), to monitor the progress made in sport training or rehabilitation protocols. An application example was developed by our research group [10] and is shown in Fig. 1. As it can be seen, flex sensors are bent with a large radius of curvature, more or less uniformly along with the strip length.

Several commercial systems have been applied to measure trunk posture and motion. Some of them are based on commercial electromagnetic tracking systems [11]. Inertial sensors were claimed to be capable of detecting the postural