

## Abstract

Advances in smart textiles, microelectromechanical systems (MEMS), wireless devices, and sensors in general, have accelerated the development of wearable and portable monitoring solutions during the past decade. Such advances and developments have been accompanied by parallel efforts in characterization and pattern recognition in an ever-increasing number of applications in numerous areas such as medicine, rehabilitation, sports, entertainment, etc. However, when considering long-term monitoring scenarios, only modest efforts have been done in the area of sensor characterization, calibration and testing. Environmental and physical factors can induce fluctuations on sensor measurements, not to mention aging and deterioration, which need to be addressed on location with restricted resources and accessibility. The present research seeks to understand and address the needs of wearable/portable systems sensor characterization through on-location strategies.

## 1. Introduction

Although much can be said of the importance of testing and design for testing in this age of Systems on Chip (SoC), mixed signal ICs, and hybrid-technology IP modules sharing common silicon; only modest attention is being paid to this aspect of design within body sensor networks and wearable technology in general [1]. Considering that pervasive technology seeks long-term monitoring (when compared to laboratory settings or even hospital stays), the need for well thought out on-location sensor characterization, calibration and/or testing strategies is pivotal in order to maintain data quality and reliability. Not only are equipment and systems expected to be reused by multiple individuals—thus requiring initialization and calibration mechanisms—but the duration of the monitoring implies that they also require sensor characterization during usage. The trial or data gathering periods are now considerably longer, meaning that data loss and the impact of a failure in mid-examination has more consequences (due to the amount of data loss or the consequence to the health of the individual). Additionally, a significant portion of these systems are designed for injury prevention and medical diagnosis, which makes the reliability of the systems an imperative. While an athlete's performance seems to be of lesser concern, when considering system failures scenarios, it should be said that some designs seek “on-event” monitoring, which means the systems are expected to safeguard against injury and/or permit performance monitoring on a real-time basis during life events, making their reliability a high priority as well. Custom testing strategies tend to represent a burden for most manufacturers due to non-recurring engineering (NRE) cost, equipment involved, time-to-market delays, etc. Alternative approaches such as platform-based strategies and standardization contribute to alleviate cost and custom requirements, but they necessitate broad manufacturing consensus for their proper implementation. A distributed modular approach, on the other hand, can contribute by breaking the problem down into smaller and more manageable pieces.

## 2. Discussion

Systems based on multifunctional instrumented garments are playing an innovative role in the development of personal monitoring devices. The use of a fabric's electrical characteristics and properties has led to the development of truly “smart clothes” capable of continuously acquiring and monitoring different biomedical variables such as ECG, EMG,

respiration and activity over an extended period in a natural daily context. Sensing fabrics represent a significant advancement for the implementation of monitoring systems with enhanced comfort and autonomy. Furthermore, a tendency has been noted towards new sensing strategies that overcome the obstacles associated with current electrical sensors. Fiber optic sensors, for instance, can be applied to multiple sensing scenarios, and are advantageous due to their small size and weight, immunity to electro-magnetic interference, high sensitivity, and multiplexing capabilities (to mention just a few) [2]. A fairly new concept that is proving popular is the use of Bragg gratings within wavelength modulation sensors (Figure 1). These sensors demonstrate very high sensitivity to changes in temperature and strain.

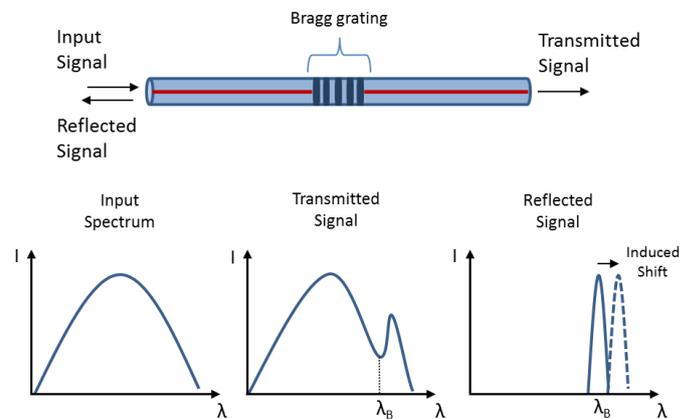


Figure 1. Fiber Bragg grating sensors sensing principle.

The characterization and, consequently, the calibration processes of these new sensors are currently performed in a very controlled in-lab environment, under specific conditions. They remain unproven when placed within smart textiles in a piece of garment subject to new variables interference. A new calibration strategy is necessarily (or imperatively) required on-site to ensure accurate sensing.

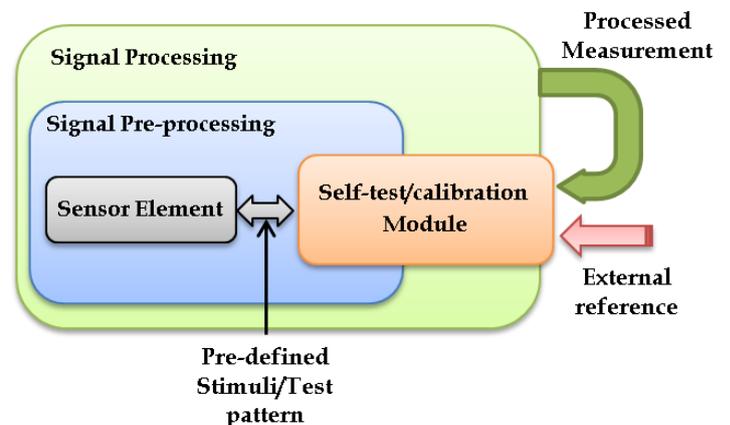


Figure 2 Self-test/calibration module [3]

Due to environmental and physical factors, sensors can suffer fluctuations on their measurements; which can be addressed during the pre-processing and/or processing stage through compensation and other strategies based on known influences. This practice is generally referred to as calibration, and is required in order to establish a known and predictable

relationship between the sensor element variation and the output signal measurement of the sensor structure. General usage, aging and other more traumatic events (damage to the structure, unforeseen environmental changes such as high humidity, high temperatures, etc.) can alter the sensor's dynamics, causing them to require re-calibration. Self-testing and self-calibration modules can address such eventualities by comparing the sensor's behavior with known values and tendencies, and introducing the necessary adjustment or declaring the sensor inoperable if need be. These feedback-based modules extend a sensor's reliability and lower processing overhead, thus safeguarding against drifting or deviating data and possibly reducing the power consumption of the overall system. A general overview of a sensor structure with a self-test/calibration module can be observed on Fig. 2.

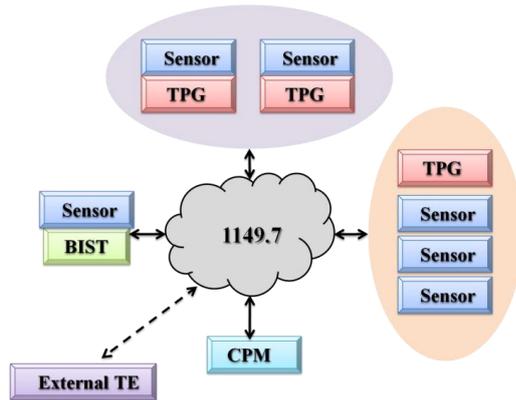


Figure 3. Conceptual multi-sensor scenario with 1149.7 interface

The built-in self-testing/calibration (BISTC) strategies have traditionally focused on performing detection, diagnosis and repair actions for a specific module, section, component or IP core. These strategies incorporate a local detection and diagnosis module which can make decisions independently or as a part of a larger testing mechanism. The increasing complexity of modern wearable monitoring systems (WMS) can seldom benefit from strategies that are too centralized, too dependent on external data or equipment, or too component-focused. Communication overhead, increased complexity and resource requirements, and greater energy expenditure; are just a few factors that limit traditional approaches. A testing/calibration strategy for WMS should be approached from a group and/or multi-sensor perspective, performing detection and diagnosis based on comparison not just of an individual sensor's measurement against a predefined behavior, but through group and multi-sensor strategies. The present research seeks to apply proven testing protocols and strategies, focusing on the 1149.7 as an interrelating mechanism, to battery based portable scenarios. Figure 3 illustrates the general target concept of the pursued approach, which considers a number of sensor scenarios, such as resource sharing, grouping, BIST and processing modules. This approach seeks to maintain data reliability through recognition of deviating degradation patterns on sensors that could provide insight into problems that a system might have due to improper sensor location, structural flaws and other factors that require the coverage provided by a group and/or multi-sensor approach.

Due to the resource limitation and trend variability that are unavoidable when performing sensor characterization on-location, resource sharing and efficient characterization strategies are compulsory. A testing bus structure is being considered in order to extend resource usage and provide a local mechanism for controllability and observability as observed on Figure 4 (a) based on the 1149.4 [4-5]. The testing bus when combined with a voltage controlled current source provides a method for on-location impedance characterization of the target passive sensor

(as seen on Figure 4 (b)), thus providing a means for correlation establishment between sensor measurement and output. A number of approaches can then be applied to the recorded data in order to ascertain behavior patterns and thus establish calibration parameters and fault scenarios. Among the approaches being considered for varying multi-sensor scenarios, in order to identify strategies for sensor status determination, are: group comparison (through parameter comparison of pre-determined sensor groups), historical characterization review (through comparison of resulting data during a prolong period of time), boundary level determination (through min-max threshold comparison).

A prototype system is being developed for testing sensors such as electrodes and force-sensing resistors (common fast degrading components of today's wearable solutions) as a part of a more global testing mechanism, and in order to establish on-location sensor behavioral patterns. In parallel, characterization of the before mentioned sensors under controlled stress situations are being performed for fault scenarios determination and calibration strategy development.

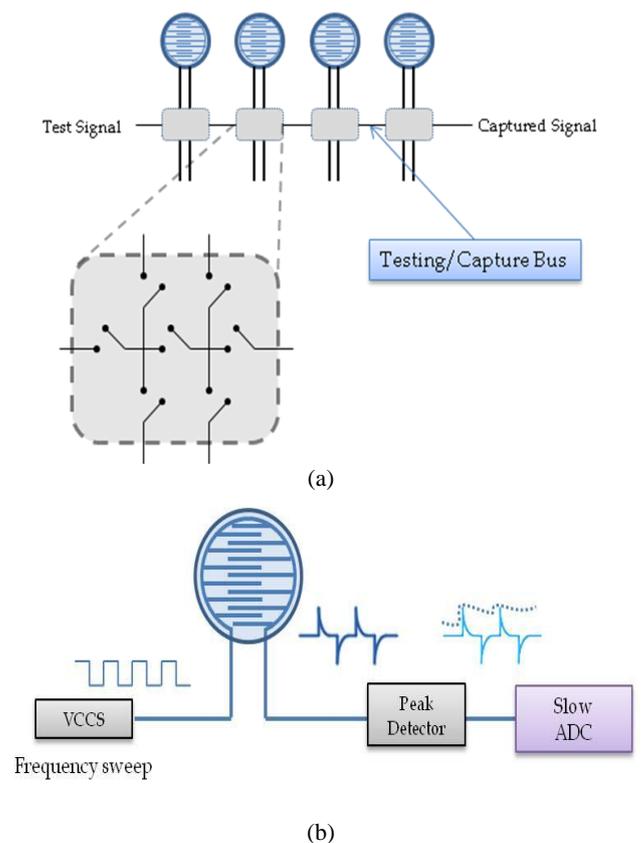


Figure 4. Proposed testing/characterization strategies: a) Testing bus for sensor arrays or multiple sensor scenarios b) Passive sensor characterization strategy.

## References

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