A Low-Cost, Built-In Self-Test Method for Resistive MEMS sensors

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A Low-Cost, Built-In Self-Test Method for Resistive MEMS sensors

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Summary

This paper illustrates the experimental application of the LIMBO method, an identification method based on binary observations dedicated to the (self-) test of integrated electronic and electromechanical systems, such as MEMS. The tested MEMS device is a micro-wire used as a heating resistor, inserted in a Wheatstone bridge. We show how the impulse response and the offset of the micro device are estimated only using binary inputs and outputs and straightforward calculations, which can easily be implemented on an FPGA. This approach only requires a 1-bit ADC and a 1-bit DAC, which makes it very amenable to integration and highlights its suitability for the test of systems based on resistive sensor and/or actuator.

Motivation and results

Self-testing and self-adjustment are very desirable features for micro-fabricated devices, because, as characteristic dimensions of electronic devices and systems become smaller, these devices become even more subject to dispersions, mostly due to variations in the fabrication process, or to changes in the operating conditions (temperature, ageing, etc.). However, most existing system identification methods [1-2] rely on a high-resolution digital measurement of the system's output using an N-bit ADC ($N \gg 1$), which is not cost effective in terms of scaling and design time. On the other hand, LIMBO (LMS-based Identification Method using Binary Observations) requires only a 1-bit ADC [3-4]. As pictured in Fig. 1, the system is stimulated with a (binary) random sequence and its Finite Impulse Response (FIR) and its offset are estimated by comparing the sign of the output signal to that of a parametric model, updated online (Fig. 2) so as to minimize data storage requirements.

We show here the very first implementation of LIMBO within an experimental setup. A two-wire resistive device, based on microwire heating resistors, shown in Fig 3, is a natural start candidate, because of its great ease of use. The value of the gauge resistance is sensitive to the ambient temperature, to the heating induced by the bias voltage and its transient behaviour, which determines the system bandwidth, may also be subject to environmental variations [5-7]. LIMBO is used to evaluate the time constant of the system (hence its bandwidth) and the offset at the output of a Wheatstone bridge, in which the gauge is placed.

The bridge is biased with a DC voltage V_b, to which a binary random input sequence $v_{in}=\pm v$ is added. The output signal V_{out} is amplified and digitized with, on one hand, a 1-bit ADC and, on the other hand, a 16-bit ADC for comparison of a classical correlation-based parameter estimation method to the results obtained with LIMBO. The measurement setup and its typical values are given in Fig. 4.

Experimental results show that the bandwidth of the trial device are estimated with 0.4% accuracy, the offset with 7% accuracy. Evaluation of the performances shows that LIMBO yields results comparable to those obtained with a standard parametric estimation method based on the 16-bit output signal (Fig. 5-6).

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Corresponding author: Legendre Olivier, U-PSUD Bat 220, 91405 Orsay Cedex, (+33)169154098, legendre.o@gmail.com.
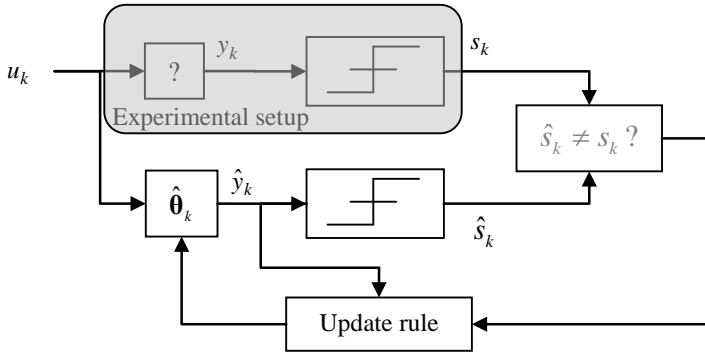
$$1 - \text{Define } \boldsymbol{\varphi}_k = \begin{bmatrix} 1 & u_k & \cdots & u_{k-L+1} \end{bmatrix}^T .$$

$$2 - \text{Calculate } \hat{y}_k = \boldsymbol{\varphi}_k^T \hat{\boldsymbol{\theta}}_k .$$

$$3 - \text{Update } \hat{\boldsymbol{\theta}}_k \text{ depending on } \hat{s}_k = sign(\hat{y}_k)$$

$$a - \hat{s}_k = s_k \Rightarrow \hat{\boldsymbol{\theta}}_{k+1} = \hat{\boldsymbol{\theta}}_k .$$

$$b - \hat{s}_k \neq s_k \Rightarrow \hat{\boldsymbol{\theta}}_{k+1} = \hat{\boldsymbol{\theta}}_k - \mu \frac{2\hat{y}_k}{\boldsymbol{\varphi}_k^T \boldsymbol{\varphi}_k} \boldsymbol{\varphi}_k$$

$$4 - \text{Normalize } \hat{\boldsymbol{\theta}}_{k+1} .$$

Fig. 1 - Block diagram of the LIMBO method. The measured output s_k are ± 1. The inputs u_k may also be binary.

Fig. 2 - At sample k, the offset at the input of the 1-bit ADC is given by $\hat{\boldsymbol{\theta}}_k(1)$, the unknown impulse response by $\hat{\boldsymbol{\theta}}_k(2:L+1)$.
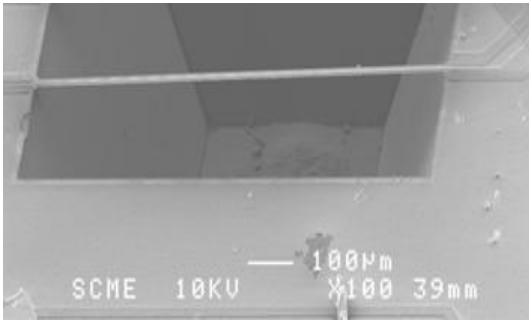

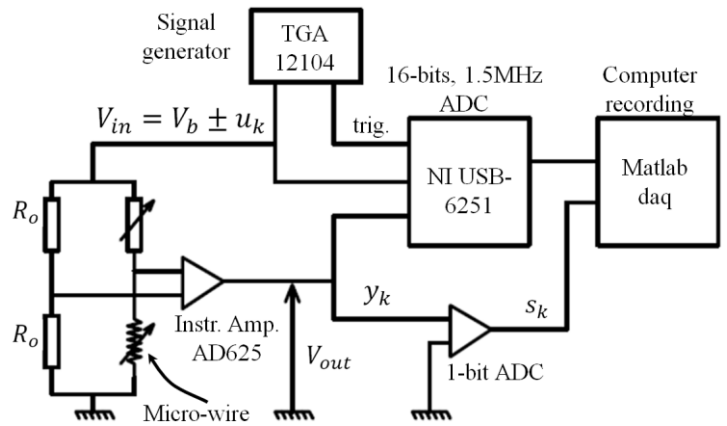Fig. 3 - SEM of the microwire used for the evaluation of LIMBO.

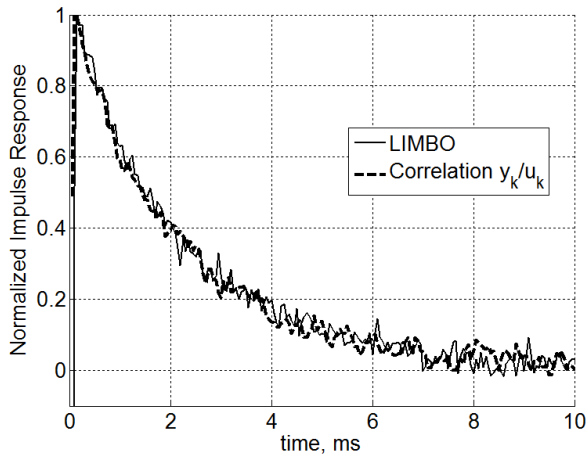Fig. 4 – Experimental setup. The resistor in the upper-right branch is used to adjust the offset.

Fig. 5 – Impulse response estimated with LIMBO (continuous line) based on 2×10^4 samples (1s) of u_k and s_k. Impulse response estimated from the correlation of 2×10^4 samples of u_k and y_k (dotted line).
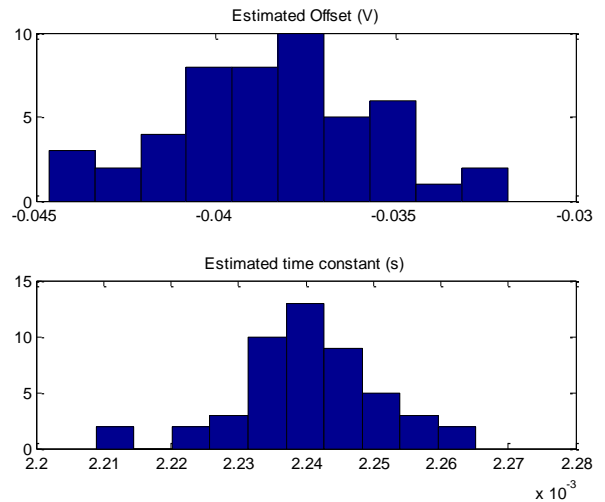

Fig. 6 – Histograms of the offset and time constant estimated with LIMBO, based on 50 1s-long measurements. Increasing the observation length results in an increased accuracy.