A MEMS triple sensing scheme based on nonlinear coupled micromachined resonators

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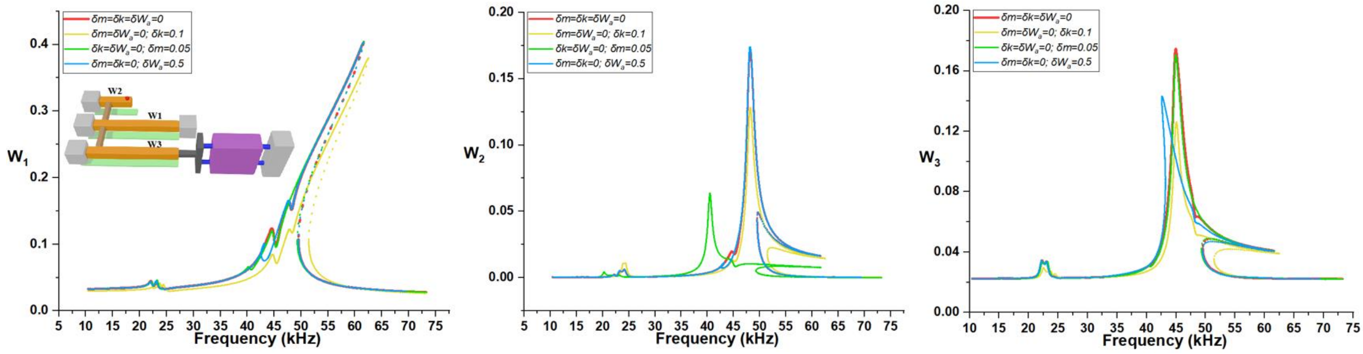
Abstract. In the past few decades, advances in micro-electromechanical systems (MEMS) have produced robust, accurate, and high-performance devices. Extensive research has been conducted to improve the selectivity and sensitivity of MEMS sensors by adjusting the device dimensions and adopting nonlinear features. However, the sensing for multiple parameters typically relies on combining several separate MEMS devices. In this work, a new triple sensing scheme via nonlinear weakly coupled resonators is introduced, which could simultaneously detect three different physical stimuli (including vertical acceleration) by monitoring the dynamic response around the first three lowest modes. The Euler-Bernoulli beam model with three-modes Galerkin discretization is used to derive a reduced-order model considering the geometric and electrostatic nonlinearities to characterize the resonator's nonlinear dynamics under the influence of different stimuli. The simulation results show the potential of the nonlinear coupled resonator to perform triple detection.

Introduction

Resonant MEMS sensors rely on the resonance frequencies' variation led by the ambient environment's influence in different ways. The parameters related to the resonance frequencies include the resonator's mass, stiffness, and geometry [1]. Past research on this topic focused on the single parameter sensing and corresponding performance enhancement. This work investigates multi-parameter sensing by introducing different stimuli to different resonators in a single coupled system. To investigate this scheme and its nonlinear dynamics, a theoretical model and simulation are performed.

The triple sensing methodology is demonstrated in three aspects in this sensor design. As shown in the inset of Figure 1(a), the middle bridge resonator W_1 will be heated electrothermally, experiencing convective cooling (or heating) from the target gas. The thermal expansion will change the bridge's stiffness and hence the system resonance frequency [2]. At the same time, the tip of cantilever resonator W_2 will be coated, causing a mass perturbation (as absorbing the target gas) and leading to a frequency shift of the system's resonance frequency. The third bridge resonator W_3 connects to an external mass with springs, used for sensing acceleration in the vertical direction. The variation of resonance frequency is associated with the axial stress of the bridge, which changes with the direction and magnitude of the acceleration [3].



(a) (b) (c)

Figure 1: Frequency response under $V_{DC1} = V_{DC3} = 40V,\ V_{DC2} = 10V,\ V_{AC1} = 7.5V$, and different perturbations: (a) Bridge response W_1. (b) Cantilever resonator W_2. (c) Bridge response W_3. Dotted lines denote unstable branches. Amplitudes W_1, W_2, and W_3, mass and stiffness δm and δk are non-dimensional; acceleration δW_a is dimensional (m/s^2). The inset of (a) shows a 3D sketch of the proposed coupled device.

Results and Discussion

The concept of a multi-stimuli sensor has been investigated, as shown in Figure 1, using a novel design comprising multiple resonators, where each resonator's response corresponds to a specific stimulus: (*i*) the bifurcation jump in bridge response W_1 is influenced by stiffness perturbation δk; (*ii*) the peak in cantilever resonator W_2 is influenced by mass perturbation δm and (*iii*) the peak in bridge response W_3 is influenced by acceleration perturbation δW_a. These preliminary results, developed via long-time integration combined with shooting technique, show the potential of accurately sensing three different parameters through monitoring the first three lowest modes of a single coupled structure as well as the rich dynamic of the proposed device. The full nonlinear response dynamics and the influence of the actuation level, damping, and geometry will be investigated as part of the future work.

References

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