A method for measuring the mass of multiple substances simultaneously in viscous environments

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Abstract. Resonant microsensors have received much attention from researchers because of their low cost, small size, and high sensitivity. Martini et al. proposed a structure for simultaneously measuring the mass of multiple substances. Because of the effect of environmental viscosity, the method based on the frequency response curve under external excitation cannot be used. We propose a method using self-excitation to overcome this difficulty. The feasibility of our proposed method is experimentally verified by using a macro-scale apparatus.

Introduction

Resonant microsensors are widely used to measure the mass of chemical or biological particles because of their low cost, small size, and high sensitivity. In previous researches, resonant microsensors typically consist of a single microcantilever with a functionalized surface. When the target analytes bond to the surface, the mass can be known by observing the resonance frequency shifts of the microcantilever. To measure the mass of multiple substances simultaneously, Martini et al.[1] have proposed a new structure using a shuttle mass coupled with microcantilevers. Under the external excitation to the shuttle mass, the shifts of resonance frequencies of the microcantilevers can be detected from the variations of peaks of the frequency response curve, which is obtained by sensing the displacement of the shuttle mass. However, in high viscous environments, because the peaks are ambiguous[2], the method based on external excitation is not applicable. Based on the characteristics of self-excited vibration, we consider compensating for the viscous damping effect by actuating the shuttle mass based on the feedback control. The feasibility of our proposed method is experimentally verified from the experiments using a macro-scale experimental apparatus.

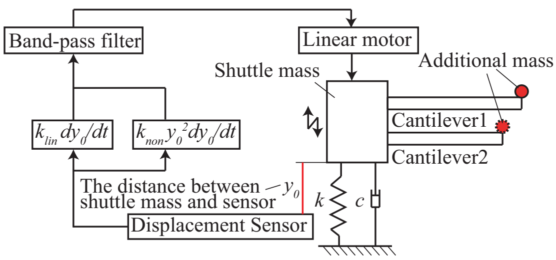

Figure 1: Schematic of the proposed method

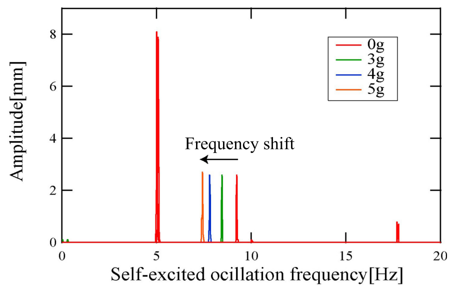

Figure 2: FFT spectrum results when the mass is on cantilever1

Results and discussion

The schematic of our proposed method is shown in Figure 1. Additional masses can be fixed at the front of cantilevers 1 and 2 coupled with a shuttle mass. In order to produce the self-excited oscillation, the sensor measures the displacement signal of the shuttle mass. Moreover, the linear and nonlinear feedback is established by using this signal. The k_{lin} and k_{non} represent the linear and nonlinear feedback coefficients, respectively. Their functions are compensating for the viscous damping effect in environments and obtaining a steady-state amplitude. A band-pass filter is used to change the self-excited vibration mode and prevents the influence of the phase difference on the experiments. The output signal from the band-pass filter is finally transferred into a linear motor which provides the excitation force to the shuttle mass.

In two sets of preliminary experiments under the self-excited vibration conditions of the shuttle mass, some additional mass is fixed to cantilever 1 or 2, respectively. In Figure 2, the FFT(Fast Fourier Transform) spectrum results indicate that only the resonance peak corresponding to the cantilever with additional mass is significantly shifted. As the magnitude of additional mass increases, the resonance peak shifts become larger. Then the relationship between the self-excited oscillation frequency and the magnitude of additional mass is experimentally examined. As a result, it can be summarized that under self-excited vibration conditions of the shuttle mass, the cantilever on which the mass is fixed (cantilever 1 or cantilever 2) and the magnitude of additional mass can be known simultaneously from the vibration mode and the corresponding response frequency shifts.

References

[1] B. E. Martini et al. (2008). A single input-single output coupled microresonator array for the detection and identification of multiple analytes. *Appl. Phys. Lett* **93(5)**: 054102.

[2] D. Endo et al. (2018). Mass sensing in a liquid environment using nonlinear self-excited coupled-microcantilevers. *J. Microelectromech. Syst* **27(5)**: 774-779.