3P3-8

Fundamental study on self-sensing of piezoelectric manipulator

圧電型マニピュレータのセルフセンシングに関する基礎的研究

Kenta Suzuki[1‡], Sze Keat Chee [2] and Takeshi Morita[1] ([1] Grad. School of Frontier Sciences, The Univ. of Tokyo; [2] Mechano Transformer Corp.)
鈴木 健太 [1‡]，徐 世傑 [2]，森田 剛 [1] ([1] 東大院 新領域, [2] メカノトランスフォーマ)

1. Introduction

In micro-manipulation, it is impotant to sense gripping state or grasping force in order to eliminate damage of the handling object. In addition, in case of cell manipulation or robot surgery, softness or viscosity detection of biotissue such as cells, blood vessels and organ, makes it possible to diagnose pathologically.

General sensing in manipulation system is conducted by strain gauges attached to the grippers; however, softness or viscosity of objects cannot be obtained and attachment of sensors prevents miniaturization of manipulators.

In this study, we propose a self-sensing system of piezoelectric micro-manipulators, in which the gripping motion drive and the sensing are simultanously conducted. It utilizes a piezoelectric material not only for driving but also for sensing. By monitoring electric characteristics of the piezoelectric material, gripping conditions, grasping force and objects' properties can be measured.

As a fundamental study, we demonstrated the principle of self-sensing the contact state between a piezoelectric actuator and an object in this report.

2. Principle

2.1 Principle of sensing objects

An equivalent circuit of a piezoelectric material around resonant frequency is represented as **Fig. 1**. When an object is attached to the tip of the piezoerectric material, equivalent mechanical impedance is connected to the mechanical terminal of the equivalent circuit. Mechanical properties of the object attached to the piezoelectric material can be measured from the frequency characteristics of the piezoelectric material.

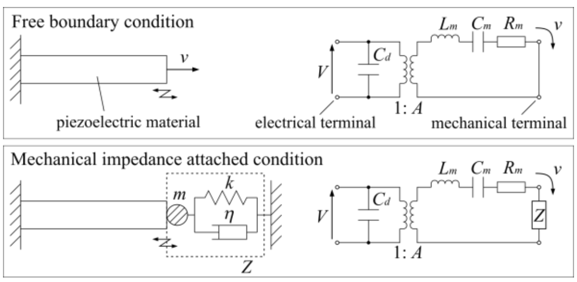

Fig. 1 Equivalent circuits with various boundary conditions.

2.2 Principle of self-sensing

In this study, a piezoelectric material for gripping motion is also used for sensing the characteristics of the object. The operation principle is shown as **Fig. 2**.

AC voltage for sensing is superimposed on the driving gripper voltage. Amplitude of the sensing AC voltage has to be small enough for little influence on the gripping motion. The current flowing to the piezoelectric material is measured by a current probe and only the sensing frequency components was extracted by a lock-in amplifier. From the amplitude or the phase of current at sensing frequency, conditions at the tip of manipulators can be detected. In this way, driving and sensing can be simultanously performed by using one piezoelectric material.

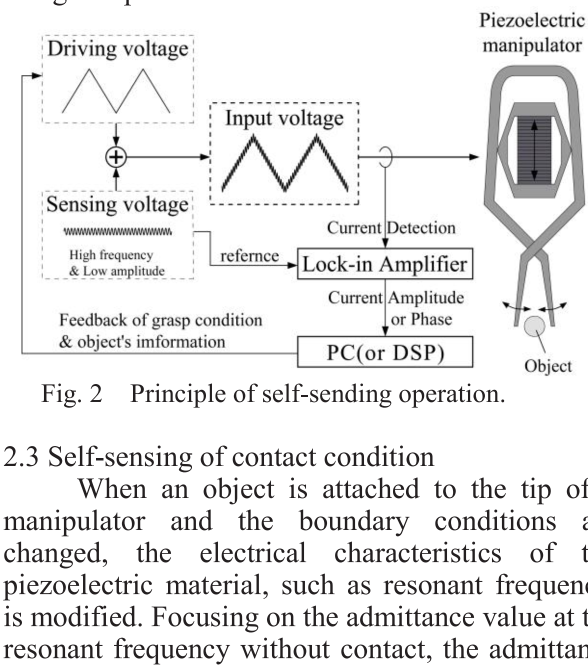

Fig. 2 Principle of self-sending operation.

2.3 Self-sensing of contact condition

When an object is attached to the tip of a manipulator and the boundary conditions are changed, the electrical characteristics of the piezoelectric material, such as resonant frequency, is modified. Focusing on the admittance value at the resonant frequency without contact, the admittance value at this frequency is expected to decrease dramatically when the manipulator is attached to the object because the resonant frequency shifts. By continuous monitoring of the admittance at the resonant frequency under free boundary conditions, it is possible to detect precisely whether the gripper is in contact with an object or not.

3. Experimental method

As shown in **Fig. 3**, a piezoelectric actuator with displacement enlarging mechanisms was fixed to a positioning stage and the output part of the actuator was faced to the fixed metal plate. The plane shape of the output part was a rectangular shape of 6.0 x 2.4 mm^2. DC voltage for driving motion and AC voltage for sensing were combined and applied to the actuator. The sensing AC voltage was fixed to 10 mV_{p-p} and same to the resonant frequency under free boundary conditions. In ideal situation, this frequency is constant; however, the resonant frequency is changed by applying DC voltage to the piezoelectric material because its polarization structure is changed. Therefore, in advance, we measured relationship between DC voltage input and the resonant frequency under a free boundary condition. According to this relationship, the sensing frequency was continuously changed around 8.7 kHz as a function of DC voltage. Driving DC voltage was increased from 0 V to 40 V in steps of 0.5 V. As DC voltage was increased, the output part approarched the facing metal plate. When 1 V of the DC voltage was applied to the actuator, the output part was moved about 2.5 μm.

The self-sensing experiments were carried out with three initial conditions. At first, the actuator was driven without the facing metal plate and next, the initial gap between the actuator and faced metal plate was set as 50 μm and the last set as 100 μm. In these conditions, the admittance value at sensing frequency was measured. Furthermore, in order to confirm the contact state in another way, the impedance between the actuator and the metal plate was measured by a LCR meter. **Fig. 4** shows photos of the experimental set-up.

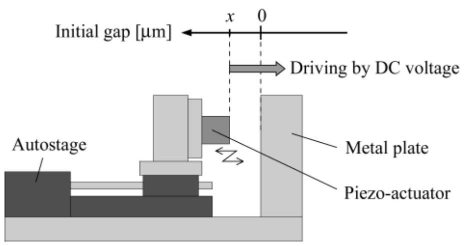

Fig. 3 Set-up for self-sensing contact detection.

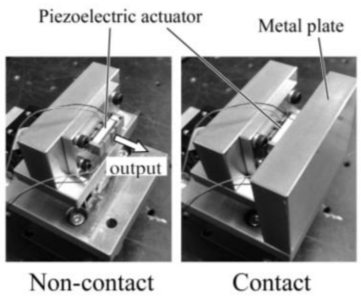

Fig. 4 Photos of the experimental set-up.

5. Results

Change of the admittance value at the resonant frequency under free boundary conditions is shown as **Fig. 5**. The admittance was decreased to less than 1/10 by contact. We identified the driving voltage for the contact point as 14 V when the initial gap was 50 μm and as 28 V when 100 μm from the impedance measurement between the actuator and the metal plate. The initial change of the admittance value was observed when the gap was less than 20 μm.

This results show the mechanical impedance of air between the tip of the actuator and facing metal plate could be detected when the gap between them was less than 20 μm.

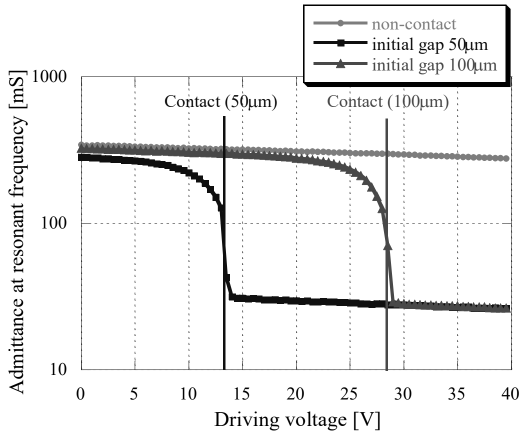

Fig. 5 Admittance decrease at resonant frequency caused by contact to a metal plate

6. Conclusion

We proposed a self-sensing system of piezoelectric manipulators. We carried out fundamental experiments for self-sensing contact state and confirmed that the contact state between the piezoelectric actuator and the fixed metal plate could be detected by measuring the admittance value of the piezoelectric actuator at the resonant frequency under free boundary conditions.

As further studies, we aim to detect the grasping force or the mechanical impedance of soft objects by our self-sensing method.

References

1. H. Hachiya, S. Ohtsiki and M. Tanaka: Jpn. J. Appl. Phys. **33** (1994) 3130.
2. Sun. XT, Chen. WH, Tian. YL, Fatikow. S, Zhou. R, Zhang. JB and Mikczinski. M: Rev. Sci. Instrim. **84**, 085002(2013).
3. S. Omata, Y. Murayama and C. E. Constantinou: Sens. Actuators A. **112** (2004) 278.
4. H. Ikeda and T. Morita: Sens. Actuators A. **170** (2011) 147.