Complete open loop control of hysteretic, creeped and oscillating piezoelectric cantilevers.

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***Abstract*— The feedforward compensation of nonlinearities, i.e. hysteresis and creep, and unwanted vibrations in micromanipulators is presented in this paper. The aim is to improve the general performances of piezocantilevers dedicated to micromanipulation/microassembly tasks. While hysteresis is attenuated using the Prandtl-Ishlinskii inverse model, a new method is proposed to decrease the creep phenomenon. As no model inversion is used, the proposed method is simple and easy to implement. Finally, we employ an input shaping technique to reduce the vibration of the piezocantilevers. The experimental results show the efficiency of the feedforward techniques and their convenience to the micromanipulation/microassembly requirements.**

***Note to Practitioners*—The works presented in this article are motivated by the high performances required in micromanipulation and microassembly tasks. Such a domain requires high accuracy, sometimes submicrometric, and stability of the micromanipulators. While piezoelectric cantilever structures are very widespread in this domain, their nonlinearities and vibrations undeniably limit their performances such as accuracy and overshoots. This may be detrimental for the micromanipulation/microassembly tasks. Feedback control techniques could easily improve their performances but the sizes of accurate and large bandwidth sensors do not make them easily embarkable for micromanipulation/microassembly systems. Thus, controllers without sensors are of great interest. In this paper, we show that open loop control techniques (also called feedforward techniques) can improve the general performance of piezocantilevers dedicated to micromanipulation/microassembly tasks. We notice that the techniques can also be applied to other nonlinear and oscillating systems.**

***Index Terms*— Piezoelectric cantilever, microassembly/micromanipulation, hysteresis compensation, creep compensation, vibration compensation, input shaping.**

I. Introduction

Nowadays, miniaturized systems which integrate more intelligence and functionalities are required more and more. These systems are either micromechanisms (micro ball bearings, microgears, micromotors), micro-optical systems (switches, lasers) or hybrid Micro-Opto-Electro-Mechanical-Systems (MOEMS) like micro-scanners, microspectrometers, or micro-coils [1] [2] [3] [4] [5]. To produce them, monolithic microfabrication can be used but new perspectives are opened with micromanipulation/microassembly techniques, such as hybrid microassembly [6] [7].

One of the main characteristics of micromanipulation/microassembly systems is the high accuracy that they must have to perform tasks. According to the sizes of the manipulated microparts, the required accuracy may be submicrometric. For instance, fixing a micro lens at the tip of an optical fiber with 1μm of relative positioning error or 0.4μrad of orientation error may cause a loss of 50 % of the light flux [8]. In order to reach the required accuracy, microrobots, micromanipulators and gripping tools are designed differently from classical robots and manipulators. Depending on the nature of the micromanipulation/microassembly tasks, and notably on the shape of the manipulated microparts, several gripping tools can be used: microgrippers, needles, vacuum grippers, ice grippers, etc. For flexibility and accuracy reasons, microgrippers are very efficient [7]. Most of positioning and gripping systems are often based on active materials in order to avoid mechanical clearances and then to increase the accuracy. Among active materials, piezoelelectric ones are widespread and their use continues to grow due to their fast response time, high resolution and sensor capabilities. Piezoelectric materials are notably appreciated and very common in piezotube scanners for AFM microscopes, in piezocantilevers and microgrippers for micromanipulation/microassembly and in actuators for step-by-step microrobots. In the case of micromanipulation/microassembly, piezocantilevers and piezoelectric microgrippers (composed of two piezocantilevers) especially offer the possibility to estimate and to control the force at the same time as the positioning control [9] [10].

Unfortunately, like other active materials, performances of piezocantilevers (and piezoelectric materials in general) are strongly affected by nonlinearities. These nonlinearities, which are the hysteresis and the creep, appear in the voltage-strain transfer [11]. While piezoelectric materials present nonlinearities with large electric fields, bending structures (cantilevers) suffer from poorly damped vibrations.

Hysteresis and the creep indeniably influence on the positioning repeatability and the accuracy of the micromanipulation/microassembly systems. It also decreases the accuracy of the force estimation if such a technique is used in the systems. In addition, the vibration critically influences overshoot of micromanipulation forces and may cause damages of manipulated fragile microparts (biological parts, optical parts, etc.) or conversely a rigid micropart may cause the damage of a micromanipulator. Finally, controlling the force may make a release task successful in the presence of adhesion forces.

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