Release Method of Microobjects Based on Piezoelectric Vibration

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Abstract: A release method of microobjects is presented based on the piezoelectric vibration. To achieve an effective release, the piezoelectric vibration is added to overcome adhesion force happened in the microoperation. This technique employs inertia force to overcome adhesion force, thereby achieving 90% repeatability with a releasing accuracy of 4 ± 0.5 μm, which was experimentally quantified through the manipulation of 20—80 μm polystyrene spheres under an optical microscope. Experimental results confirmed that this adhesion control technique was independent of substrate. Theoretical analyses were conducted to understand the releasing mechanism. Therefore, the micromanipulation system proved to be effective for active releasing of micromanipulation. A novel gripper structure with triple finger is devised. In the design, three cantilevers are considered as the end effectors of the fingers, driven by piezoelectric ceramic transducer (PZT). Tungsten tipped probes are used to pick and place the micro objects.

Key words: microelectromechanical systems (MEMS); micromanipulation; piezoelectric vibration

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0 Introduction

Micromanipulation and microassembly are essential for serving as enabling techniques in a wide variety of applications to biological and biomedical research, as well as in the assembly of microelectromechanical systems (MEMS) and microelectronic devices[1-4]. With the development of miniaturization, decreasing the scale brings us to technological limits such that it seems to be necessary to use intrinsic properties of the considered scale. Among the challenges, a long-standing difficulty in the manipulation is the release of microobjects from the end-effector due to the adhesion forces at microscale. Scale effects cause adhesion forces including the van der Waals force, electrostatic force, and capillary force to dominate volumetric forces (e. g., gravity)[5].

Currently, there are two types of release methods in the micromanipulation systems, passive release and active release. Passive release techniques mainly depend on the strong adhesion substrate. In consideration of adhesion and rolling resistance factors[6], an Au-coated substrate is used for both picking and releasing operation. Microspheres were rolled on the special substrate causing the fracture of the sphere-substrate interface and the sphere-tool interface, respectively. Similarly, it was also demonstrated that miniscule glass spheres had been fixed on a sample table by an ultraviolet cure adhesive[7]. A commonality of passive releasing technique is the dependence on surface properties, time consuming, and poor in repeatability.

Differently, active release methods intend to detach the microobject from the end-effector without touching the substrate. A common method of active releasing is using vacuum tools[8-9] to create a pressure difference for picking and releasing. However, miniaturization and accurate control of vacuum tools are difficult, and sometimes its use in a vacuum environment is limited. In

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Ref. [10-11], freezed tweezers were used to pick microobjects, and thawing of the ice was used to release microobjects. The approach requires a complex end effector and is limited to micromanipulation in an aqueous environment.

Micromanipulation systems with MEMS microgrippers[12-13] have also been widely reported. As a key technology, these double-ended microgrippers could pick the microobjects easily and provide a sufficient clamping force. However, it is difficult to achieve effective releasing of microobjects since the adhesion force between the objects and one of the gripping arms. Some methods are used to reduce the adhesion force, for example, surface roughening of gripping arms[14], chemically coating gripping arms[15], and changing the surface characteristics[16]. Nevertheless, the effectiveness of gripping arm treatment for releasing is limited since the residual adhesion forces is still strong enough to keep the micro object adhered to a gripping arm. An active releasing strategy by using an MEMS microgripper integrated with a plunging structure between two gripping arms was presented in Ref. [17]. The 7.5—10.9 μm microspheres were picked and released easily.

Considering the operation strategy, a type of active releasing makes use of mechanical vibration[18-19]. The vibration method takes advantage of inertial effects of both the end-effector and microobject to overcome adhesion forces. The landing radius of the released object has been calculated and simulated in Ref. [20], however, the accuracy of the single vibration has not been experimentally quantified.

Here, we present a micromanipulation system based on active picking and releasing strategy by adhesion control with compound vibration. The operation tools consist of an MEMS microgripper and a piezoelectric ceramics, as shown in Fig. 1. The microgripper is actuated by electrostatic actuator and fixed on the piezoelectric ceramic transducer (PZT). This strategy retains the advantage of double-ended tools for picking up microobjects. The vibration caused by the PZT is capable of placing a microobject adhered to a gripping arm to a desired destination on the substrate, thereby enabling highly repeatable releasing with a high accuracy.

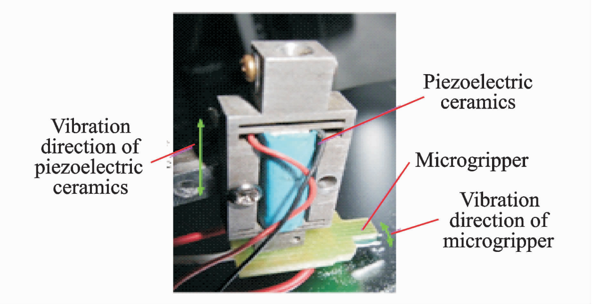


Fig. 1 Composite operational tool

1 Release Control of Vibration

The adhesion phenomena are mainly a result of intermolecular potentials, as expressed by Van der Waals forces. Capillarity and electrostatic are also environment-dependent forces that contribute to the adhesion. For microscale objects, these forces have higher magnitudes than the gravitational force and they are mainly attractive. Nevertheless, they depend on the inverse square or cube of the distance between the surfaces, for example, for Van der Waals, and their influence becomes obvious in contact. A minimum amount of force is thus necessary to separate two mediums in contact. This force is commonly called the pull-off. In the case of a sphere (radius R_b) on a planar surface, its expression is approximately given by the JKR (for the lower boundary) contact models [20].

$$F_{\text{ext}} > \frac{3}{2}\pi R_b \gamma_{bb} \tag{1}$$

where γ_{bb} is the adhesive energy between microobjects.

The dynamic method mainly takes advantage of inertial effects[20]. Fig. 2 shows the status of microsphere after separation by the dynamical effects of single-arm. There are two Van der Waals forces on the sphere, one from the cantilever and the other from the substrate, as shown in Fig. 2. Suppose F_p is the Van der Waals force from the cantilever, F_s is from the substrate, and F_g stands for the gravity. The dynamic model after separation is

$$\ddot{z} = (\cos\theta \cdot F_p - F_s - F_g)/m \tag{2}$$

$$\ddot{x} = \sin\theta \cdot F_p/m \tag{3}$$

where the positive direction of θ is defined to be clockwise.

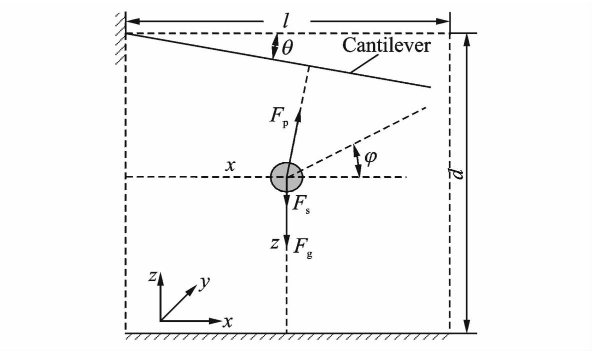


Fig. 2 Non-contact force on sphere after separation

By Eqs. (2), (3) we can see that the larger angle $\theta(\leqslant 90^\circ)$ is, the easier it is to achieve the release in x_1 direction. Theoretically, when $\theta=90^\circ$, the location of microsphere changes into the beam side from the bottom of the beam.

In actual gripping operation, the adhesive forces are more complex between the microsphere and the two end arms of microgripper, and the microsphere is usually adhered at a single end beam. The release of the microsphere is accomplished by combining the x-direction vibration and the z-direction vibration. The arms of microgripper can vibrate both vertically and horizontally in the gripping direction. In the release process, the microobject can be close to the substrate. This way could use the microscale force of the substrate to achieve a more satisfactory release.

2 Experiments of Dynamic Release

A test setup (Fig. 3) was established to characterize the performances of the dynamic manipulation. This typical system consists of macro moving precise positioning stages, piezoelectric actuator, microgripper and micro-vision systems. A composite operational tool consisting of the PZT and microgripper was mounted on the positioning stages at a tilting angle of 30°. The test was carried out at room temperature of 20±3 ℃ with relative humidity of 40±5%.

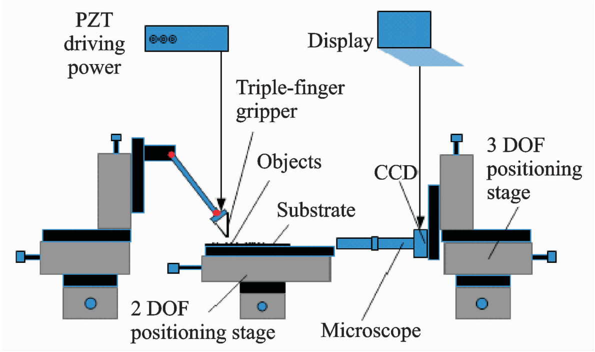
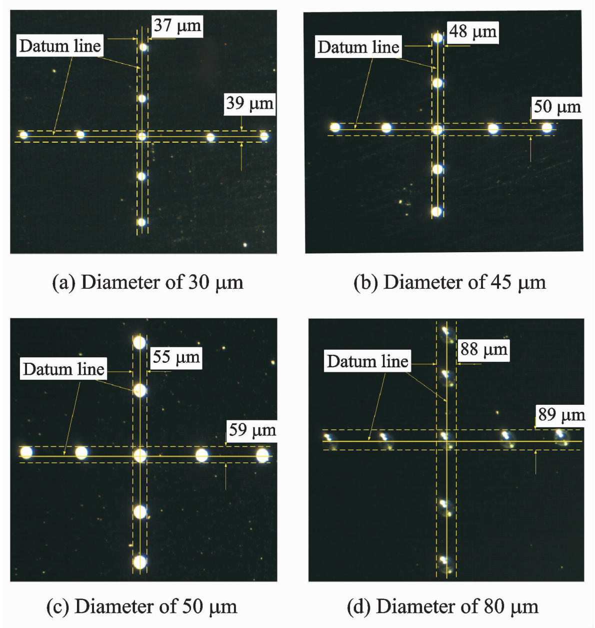


Fig. 3 Experimental setup of manipulation system

Fig. 4 shows the result of a series releasing of microspheres. The releasing point range is calculated at a fixed coordinate system. We can obtain an accuracy of 4±0.5 μm for the microspheres release. In Fig. 4, the spheres with diameters of 30, 45, 50, 80 μm are arranged, respectively. The cross-shaped arrangement is conducive to the calculation of position accuracy. The solid lines are the datum, and dotted lines are the boundary region of release. The deviation between the lines can be calculated as the accuracy of release.



(a) Diameter of 30 μm (b) Diameter of 45 μm

(c) Diameter of 50 μm (d) Diameter of 80 μm

Fig. 4 Stability of microspheres release experiments

3 Design of Triple-Finger Tool

The experimental system with triple-fingers tool is designed, as shown in Fig. 5. The system employs a novel microgripper with a triple-finger structure to impact on a microobject that gains sufficient momentum to overcome adhesion forces. The single operating arm is driven by the PZT. The prototype of the discrete triple-finger tool is shown in Fig. 6.

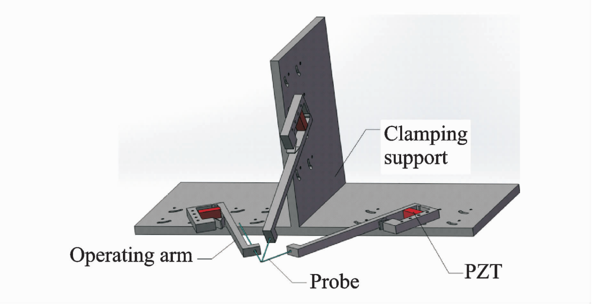


Fig. 5 Microgripper with triple-finger structure

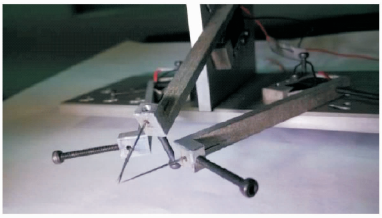


Fig. 6 Prototype of discrete triple-finger tool

The movement of probes is controlled by the driving power of piezoelectric ceramic. The minimum diameter of the special probe′s tip can reach 0.2 μm. According to the stroke of the gripper, the spheres, whose size between 20 μm and 80 μm, could be picked up and placed with the gripper. When the probes are changed, some different tools made of other materials could be assembled to the cantilever. With these grippers, some different targets could be grasped and released. Moreover, the triple-finger device could be used to do different manipulation work.

The triple-fingers gripper device is also used to perform a classic example of microobject manipulation. The assembly of a two-layer structure requires the use of special tungsten tipped probe. The borosilicate glass sphere in a small size is hard to pick up and place. Three types of attractive forces, namely, the van der Waals force, the electrostatic force, and the capillary force, are the main impacts on the microobject manipulation. When the spheres are picked up, they would not be placed because of the adhesion forces. However, with the help of releasing probe, the target sphere would be released to overcome other forces. Tasks of pick and place of the borosilicate glass spheres were carried out.

In the experiment, the borosilicate glass spheres are the target ball which would be picked up by the gripper device. When the ball got the right place, the releasing probe would be drived by the power in a high speed to bring the sphere down. The diameter of the spheres in the manipulation is about 40 μm. In Fig. 7(a), triple-finger end effectors are used to complete the releasing operation. With the help of the releasing probe, the target sphere is placed in the platform with a high accuracy, as shown in Fig. 7(b). With the monitor, the real-time image produced through the CCD sensors could help to manipulate the balls. The left and right probes had been moved to approach the operating platform. When the left probe got the platform, and the sphere is right in the middle of the two probes, the piezoelectric actuator is controlled by the driving power to pick the sphere up depicted in Fig. 7(c). The gripper would take the sphere to the target place, and then the releasing probe put it down in a high accuracy. The two-layer structure is made by the triple-finger gripper (Fig. 7(d)). The spheres are 20 μm on the left, and the spheres on the right

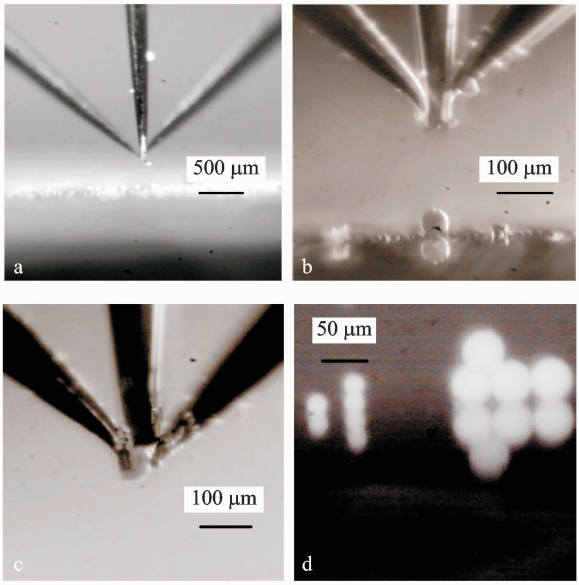


Fig. 7 Experiment of triple-fingers tool

are 40 μm. From these results, the tools are the most important factor impacted on the performance of the gripper device. The operating objects are related to the size and material of the probes. The probe-based triple-finger end effectors are more rigid than the silicon ones because of the material performance. The experiments had been repeated 200 times and results are recorded. In the releasing experiments, the spheres are 20 μm. The double-finger had released 14 spheres in 5 s per one time. The triple-finger had released 163 spheres in 1 s per one time.

4 Conclusions

A micromanipulation based on releasing strategy by adhesion control with compound vibration is presented. This operation strategy employs inertia force to overcome adhesion force achieving 90% repeatability with the releasing accuracy of 4±0. 5 μm, which was experimentally quantified through the manipulation of 20—80 μm polystyrene spheres. The piezoelectric actuator and the electrostatic driven supply the mutual perpendicular vibrations which generate enough force to overcome the adhesion forces. The manipulation mode combined PZT and the microgripper can ensure the accuracy of releasing operation. In order to increase the efficiency, the triple-finger tool is designed. Exactly 200 spheres had been picked up and placed on the platform. The sizes of these spheres range from 20 μm to 80 μm. With the help of the third finger, the sphere could be released in 1 s. The piezoelectric actuators could assure the device with a fine position reaching 0. 35 μm/V.

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