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Separable Water Supply Machine for Hydraulic-Driven Micro Device

Yudai Fujiwara[1], Tohru Sasaki[1], Masao Hebisawa[1], Shohei Hanaoka[1],
Kenji Terabayashi[1], Mitsuru Jindai[1], Kuniaki Dohda[2] & Satoshi Kuroda[3]

[1] *Department of Mechanical and Intellectual Systems Engineering, University of Toyama*
[2] *Department of Mechanical Engineering, Northwestern University*
[3] *Department of Neurosurgery, University of Toyama*

tsasaki@eng.u-toyama.ac.jp

Abstract
A hydraulically driven microdevice that we developed has both high-precision sensing and high-resolution positioning. A water-supply machine supplies and extracts water to and from the hydraulically driven microdevice, an end effector, for micro-manipulation. Controlled by the water-supply machine, the hydraulically driven microdevice handles objects and measures the amount of force acting on the end effector by measuring changes in pressure. Our previous device can measure small forces acting on the end effector. However, it is difficult to position the device when the gain in the measured force is high because the end effector moves a large amount in response to a small amount of liquid supplied, and the positioning resolution decreases. This makes the device unsuitable for micro-manipulation. High-precision sensing and high-resolution positioning have a trade-off relationship. To solve this problem, we propose a new machine called a separated water-supply machine. The part that supplies water and the part that measures pressure are separated through a flow channel. Each part is its own cylinder. The cross section of the part that supplies water is large; the cross section of the part that measures pressure is small. This enables the machine to supply water to the hydraulically driven microdevice with precision while also being highly sensitive to gain in measured force. This report describes the separated water-supply machine that we developed and the results of our evaluation of its sensing precision and positioning resolution.

Sensor, Actuator, Hydrostatic, Accuracy

1. Introduction

Micro-manipulations, microsurgery using surgical microscopes and biohandling, require careful and precise work [1, 2]. Many manipulators for micro-manipulation have been developed [3], but using them is more difficult than manual operation because of their lack of haptic sensing functions. For this reason, we developed a hydraulically driven microdevice for micro-operation that has both high-precision sensing and high-resolution positioning. Controlled by a water-supply machine, the hydraulically driven microdevice handles objects and measures the amount of force acting on an end effector. The force acting on the end effector is amplified in accordance with Pascal's Law. This enables our device to measure small forces acting on the end effector by measuring changes in pressure.

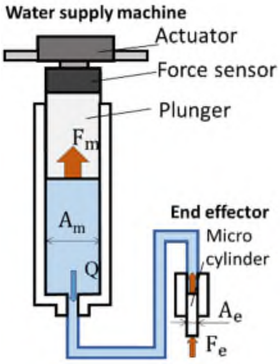


Figure 1. Non-separated water-supply machine (previous)

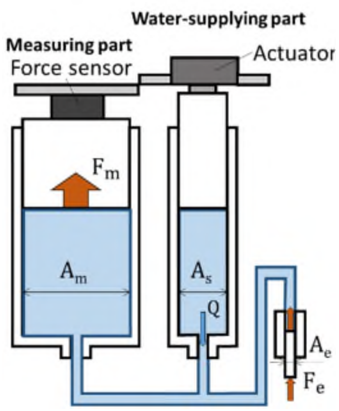


Figure 2. Separated water-supply machine (new)

However, it is difficult to position the device when the gain in the measured force is high, as it is when the cross section of the water-supply machine is large. The difficulty of positioning the device makes it unsuitable for micro-manipulation. High-precision sensing and high-resolution positioning have a trade-off relationship. To solve this problem, we propose a new machine called a separated water-supply machine. This report describes the separated water-supply machine and the results of our evaluation of its sensing precision and positioning resolution.

2. Separated water-supply mechanism

Figure 1 shows the previously developed water-supply machine. It supplies and extracts water to and from the hydraulically driven microdevice, an end effector, for micro-manipulation [4]. The force acting on the end effector is amplified in accordance with Pascal's Law by the ratio of the cross section of the hydraulically driven microdevice (A_e) and the cross section of the water-supply machine (A_m). The gain in the measured force is $G_f = A_m / A_e$. In this previously developed device, G_f is over 1000. However, as stated, positioning the device becomes difficult when the gain in the measured force is high, as it is when A_m is large. Let δ be a minimum quantity of water supplied; the positioning resolution is $Q = \delta \cdot A_m / A_e$. If A_m is large, the end effector moves a large amount in response to a small amount of liquid supplied, decreasing the positioning resolution. This renders it unsuitable for micro-manipulation. To solve this problem, we propose a separated water-supply machine. The part that supplies water and the part that measures pressure are separated through a flow channel. Each of the two parts is its own cylinder. In this machine, A_m is large, and the cross section of the part that measures pressure (A_s) is small. The gain in the measured force is $G_f = A_m / A_e$, and the resolution of the positioning is $Q = \delta \cdot A_s / A_e$. This machine can supply water to the hydraulically driven microdevice with precision while maintaining high sensitivity to gain in measured force.

3. Experimental devices

Figure 3 is a photograph of the separated water-supply machine, which is the drive system for the microdevice. A load cell is fixed to the plunger of the sensing part, i.e. the large syringe, for measuring internal pressure. The actuator rod of the linear actuator is fixed to the plunger of the water-supplying part, i.e. the small syringe, and it controls the amount of liquid supplied to the microdevice. The small syringe has a 4.9-mm inner diameter; the large syringe has a 35.5-mm inner diameter. The inner diameter of the syringe in the previous water-supply machine was 15 mm. We used two steel microcylinders as end effectors, one 0.5 and the other 1.6 mm in diameter. Figure 4 shows these end effectors. In the previous system, the amplitude ratio of the measured force was from 90 to 900; in the new one, it is theoretically from 500 to 5000.

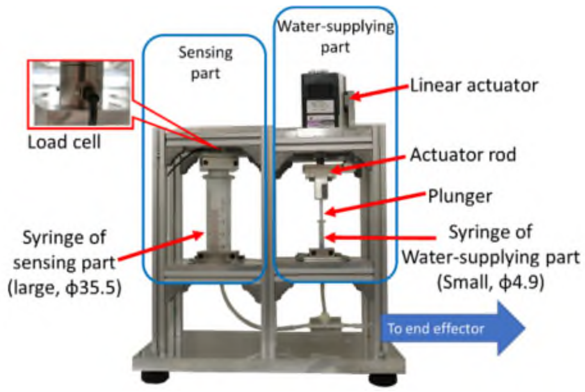
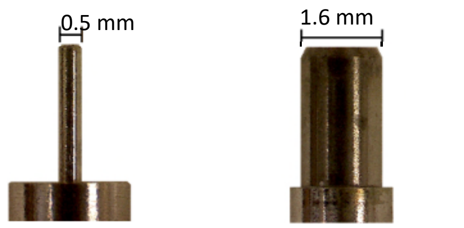


Figure 3. Separated water-supply machine



(a) Microcylinder ϕ 0.5 **(b)** Microcylinder ϕ 1.6

Figure 4. End effectors

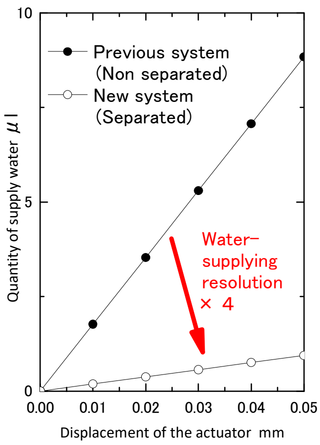


Figure 5. Supplied water quantity by displacement of actuator

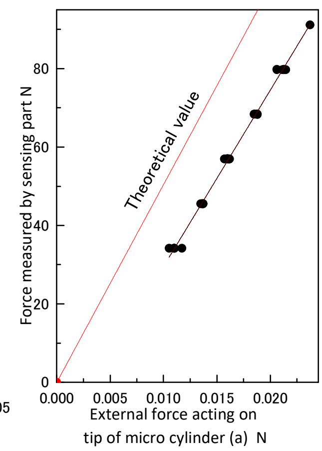


Figure 6. External force and force measured by microcylinder ϕ 0.5

4. Water-supply experiment

The linear actuator moved the small syringe 0.01 mm in accordance with a position command issued from a personal computer and supplied water to the end effector. Figure 5 shows the change in the quantity of supplied water by the displacement of the actuator. The water-supplying resolution of the new (separated) system was four times that of the previous (non-separated) system. Because the quantity of water supplied is directly proportional to the cross section of the syringe in the water-supplying part, this result agrees with the theoretical results. The new system improves the resolution of the water-supplying part, thereby improving the resolution of the end effector's positioning.

5. Measurement of force on end effectors

The microcylinders, end effectors (a) and (b), are attached to an electronic balance. The water-supply machine supplies water to microcylinder, which pushes the electronic balance. External force was measured using the electronic balance by measuring the reaction force. The force measured by the sensing part was recorded by the load cell. Figure 6 shows the relationship between the external force, i.e. the force acting on the tip of the 0.5-mm-diameter microcylinder, and the measured force. The measured force was proportional to the external force. The amplitude ratio of the force with the 0.5-mm-diameter microcylinder was 4500 times, close to the theoretical value of 5000 times; as with the cross-section ratio, the experimental and theoretical results showed good agreement. The resolution of the measured force of the new system was four times that of the previous system. In other words, the new system enabled higher measurement accuracy. These results were obtained with the two end effectors.

6. Summary

(1) We developed a new water-supply system that separates the water-supplying and sensor parts. This separation can solve the problem of the trade-off relationship between high-precision sensing and high-resolution positioning.
(2) The water-supplying resolution of the new (separated) system was four times that of the previous (non-separated) system.
(3) The resolution of the measured force of the new system was four times that of the previous system.
(4) The two end effectors obtained results similar to the theoretical results.

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