Controlled Motion of Particles in a Microchannel

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Introduction

Advanced microfluidic devices able to sort objects such as particles or cells in a microchannel are already applied in many areas in biology and chemistry. In the specific application of *in-vitro* fertilization (IVF) such devices can be beneficial in terms of time and cost efficiency. However, a device that can select and sort individual sperm cells based on their morphology and motility has yet to be developed [1]. In this work, a system is developed and characterized that uses closed-loop control to visually select and sort objects or particles in a microfluidic channel. The concept of the device is demonstrated by using silica beads with different diameters (5 µm, 10 µm, 20 µm) that are similar in size to sperm cells. To sort the beads in a cross channel with a width of 100 µm, a positioning accuracy of ±50 µm is needed. To reach the required sorting speed, the fluid flow in the system must reach 202.20 µL/h, while being able to detect and control the beads.

Materials and Methods

An open-loop system containing piezoelectric micropumps, a microfluidic chip, and a vision system (microscope and camera) was already available at the University Hospital in Basel. This open-loop system was modified for close-loop control. Different methodologies were studied for detection and identification of the beads with vision as well as for motion control. The image processing pipeline uses bead edge enhancement with a Laplacian filter, thresholding, blur, and contour detection (based on OpenCV edge following). This performed better than the Hough transform or blob-detection. A sliding-mode controller proved the most robust choice over PID, Fuzzy, and a two-point controller.

Results

The closed-loop control system developed captures and processes images, then drives the microfluidic pumps with an average loop time of 5 ±2 ms. The spatial accuracy of the controller was evaluated with different channel sizes with a square cross section (side: 50 µm and 100 µm). The position of the controlled bead varied around the target position [-11.82, 21.82] µm (mean: 5.59 µm) for the channel with the larger cross section, while a range of [-32.72, 29.55] µm (mean: -2.99 µm) was achieved for the channel with the smaller cross section.

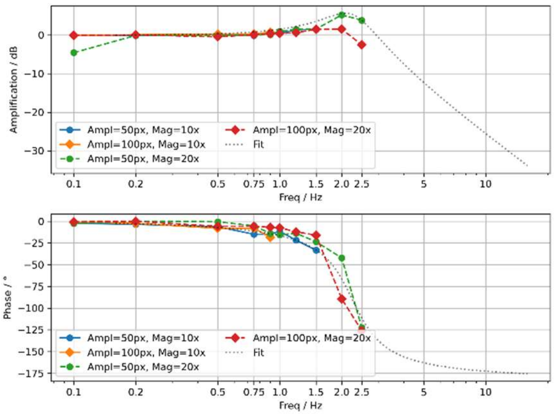

Fig. 1 Dynamic response of the system with a non-linear sliding-mode controller.

The system's frequency response is characterized as a linear, second-order, underdamped system with a cutoff frequency around 2.25 Hz (Fig. 1).

Discussion

The achieved positioning accuracy for both channels is better than the specified range of ±50 µm. The system can detect and manipulate the beads at the desired flow rate. This proves the feasibility of such a device for sorting and selecting particles in microchannels.
To optimize the system further, the resolution of the output voltage to the micropumps can be improved. A better resolution could be simulated with the given characterization of the system and a different controller might be chosen. To optimize bead detection, other vision algorithms may be pursued, such as background suppression or AI-based.

References

[1] K. Rappa, et. al. "Sperm Processing for Advanced Reproductive Technologies: Where Are We Today?" Biotechnology Advances 34, no. 5 (September 1, 2016): 578–87.

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