REAL-TIME FEEDBACK CONTROL OF DROPLET GENERATION FOR EWOD DIGITIAL MICROFLUIDICS

Jian Gong and Chang-Jin "CJ" Kim

Mechanical and Aerospace Engineering Dept., UCLA, Los Angeles, U.S.A.

Abstract

We report the successful implementation of real-time feedback control of the droplet generation process on the electrowetting-on-dielectric (EWOD) digital microfluidics. Demonstrated in the air environment in this paper, the feedback allows precise (< ±1%) droplet generation and also empowers users to prescribe the volume through software.

Keywords: EWOD, electrowetting, digital microfluidics, droplet generation

1. Introduction

Generating droplets of uniform volume is essential for the digital microfluidics systems, which use droplets as basic fluidic units. Recently we have shown that high uniformity (±%2) can be achieved by new firing sequence [1]. We have also confirmed accurate on-chip capacitive measurement of droplet volumes [1,2]. In the current paper, we develop feedback control system to defeat the random uncertainties and further improve the uniformity. Furthermore, the feedback allows generation of user-subscribed droplet volumes within a range determined by the hardware.

2. Method

Real-time feedback actuation has become possible through a new control board, capable of a fast capacitive sensing of the droplet volume and a precise construction of driving signals (Fig. 1(a)). A microcontroller from Microchip® can precisely control the high voltage driving signals for the EWOD actuation through a 14-bit digital-analog-converter (DAC) and a 32-channel on-board high voltage amplifier. A ring oscillator circuit is used to detect the capacitance between the driving EWOD electrode and the top grounding electrode, proportional droplet volume. The oscillation frequency of the circuit is inversely proportional to the capacitance and measured by a pulse counter in the microcontroller. Then the microcontroller decides the high-voltage driving signals according to the control algorithm in the program. By using a fast 20 MHz microcontroller and optimizing the program code, one cycle of sensing and driving can be completed within 1 ms. Considering the typical droplet moving speed under EWOD actuation is 1-10 mm/s, the control speed is fast enough for real-time control. An up-stream PC defines the algorithm and downloads the program into the microcontroller.

One simple but efficient control algorithm is shown in Fig. 1(b). When the frequency (f) is detected by the pulse counter, the capacitance (C) is calculated. Driving signals at the creation site and reservoir will be controlled by the algorithm according to C to bring the droplet footprint area within the desirable range (between $c1$ and $c2$). When the droplet volume is within range, both the creation site and the reservoir will be energized until the liquid neck breaks and one droplet gets generated.

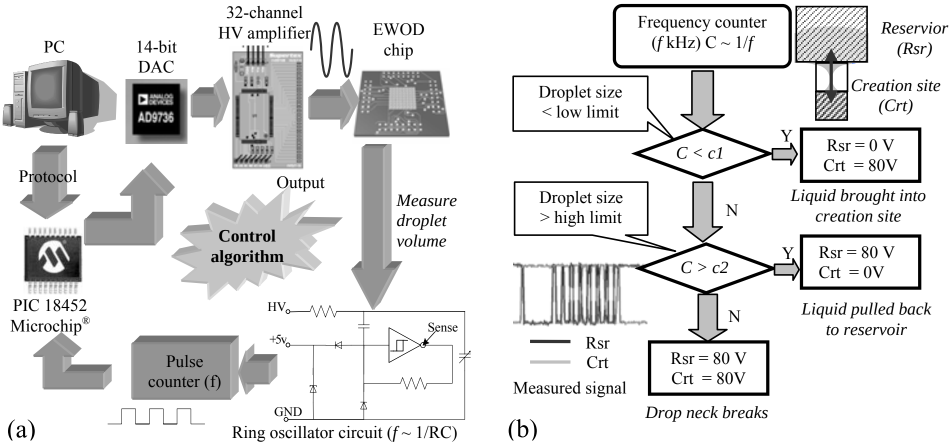


Figure 1. (a) Diagram of real-time feedback control hardware. (b) Feedback control algorithm for droplet volume control. c1 and c2 define the accuracy of droplet volume.

3. Results and discussion

Fig. 2 shows the results obtained on a printed circuit board (PCB) based EWOD chip [3] having the 1.5 mm x 1.5 mm electrodes and 100 µm high channel. We compare droplet uniformities with and without the feedback. The standard deviation of the droplet volume distribution is 5x smaller with the feedback control. Fig. 3 also shows the excellent linear relationship between the droplet volume and the control parameter $1/f \sim C$. The smallest droplet we can generate is as small as 20% of the electrode size.

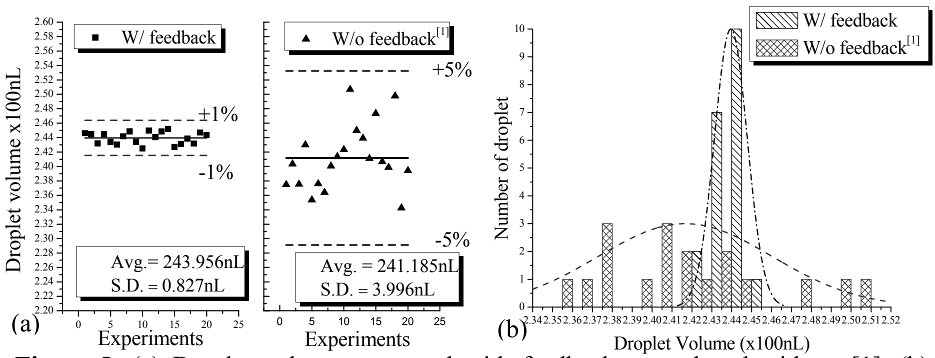
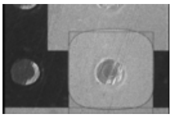


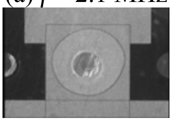
Figure 2. (a) Droplet volume generated with feedback control and without [1]. (b) Histogram of the data from (a) at every 1 nL volume increment.

With the new ability to accurately generate droplet volumes within a wide range, more sophisticated digital microfluidic operations can be designed, allowing new digital microfluidic operations not feasible before, such as high-order sample dilution. For example, for x10000 dilution, without feedback control the most efficient method is 1:1

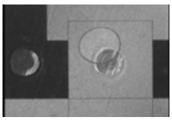
mixing and cutting, requiring 14 operation cycles. On the other hand, with feedback control and variable droplet volume (down to 20%), only 6 cycles are needed. Fewer dilution cycles also improve the concentration accuracy with smaller accumulated error.



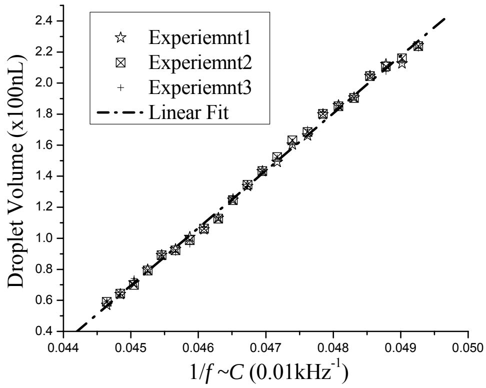
(a) f = 2.1 MHz



(b) f = 2.17MHz



(c) f = 2.26 MHz



(d) Droplet volume vs. $1/f \sim C$.

Figure 3. (a), (b), (c) are the snapshots right after droplet generation at certain feedback parameter f. (d) shows the linear relationship between volume and $1/f$ proportional to C.

5. Conclusion

We have successfully designed and implemented the real-time feedback control of the droplet generation process on the EWOD digital microfluidic chip, significantly improving the uniformity of the droplet volume (5x less standard deviation). Furthermore, the feedback allows the generation of varying volumes of droplets on a given electrode pattern. The former can improve device reliability by compensating for the uncertainties in the fabricated device and operation conditions, while the latter allows a new flexibility in designing sophisticated digital microfluidic applications.

Acknowledgements

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References

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