First Practical Realization of Switching in Microfluidic Networks

Medina Hamidović*, Uli Marta‡, Andreas Grimmer†, Gerold Fink†, Robert Wille†,
Helen Bridle‡, Andreas Springer* and Werner Haselmayr*
*Institute for Communications Engineering and RF-Systems, Johannes Kepler University Linz, Austria
†Institute for Integrated Circuits, Johannes Kepler University Linz, Austria
‡Institute of Biological Chemistry, Biophysics and Bioengineering, Heriot Watt University, UK

I. Introduction

Over the years, microfluidics has allowed transfering complex laboratory operations of conventional batch processing to a micro-scale. Miniaturization of biochemical operations normally handled in a laboratory has resulted with the development of devices known as Labs-on-a-Chip (LoCs) [1]. Exploiting the advantages of a micro-scale, LoC devices are able to perform highly complex laboratory operations with high throughput, reduced reagent consumption, high sensitivity and high cost efficiency. A typical LoC device integrates several processing elements of which each element performs a specific laboratory operation, such as mixing and diluting. The elements are interconnected and built into a fixed, static chip topology using a network of microchannels. This means that the samples to be processed will always pass the same sequence of basic processing elements which clearly limits the flexibility, effectivness and reusability of the designed LoC device.

Recently, microfluidic networks for droplet-based microfluidics (cf. [2]–[4] and references therein), have been introduced as a promising tool for realizing programmable and flexible LoC devices. Microfluidic networking describes the principle of interconnecting multiple LoC devices onto a single microfluidic chip. In particular, microfluidic networking achieves high degrees of flexibility by dynamically assigning the droplets' path throughout a microfluidic network thus enabling to target any of the interconnected LoC on the platform.

The key element in microfluidic networks is the microfluidic switch: the element inherited from conventional ICT systems. Microfluidic switches interconnect LoC devices within the network and dynamically control the path of a single or multiple droplets [2], [3]. This is accomplished by sending a controlling droplet, so-called header droplet, in front of the droplet containing the biological/chemical samples, the so-called payload droplet. Just like in ICT terminology, header droplets are only used for signaling and switching of the payload droplet, and contain no sample. The location of the targeted LoC device for the payload droplet can then be either encoded in the distance between payload and header droplet, so-called droplet by distance (DbD) switching, or in the size of the header droplet [5], so-called droplet by size (DbS) switching [6].

However, while the concepts of microfluidic networks, and relevant encoding and switching principles, have been proposed and investigated, rather few experimental works reports on the practical realization and applicability of these principles. This is mainly caused by the fact that experimental investigation of microfluidic networks requires a precise, passive, controllable and automated droplet generation element, so-called Droplet-on-Demand (DoD) element, which has been a poorly investigated element in microfluidics. Moreover, in order to generate header-payload pairs to realize DoD and DbS encoding, cascading of multiple DoD systems on a single channel, is a necessity.

In order to fully exploit the potential of microfluidic networks, we present a simple DoD system that enables generating arbitrary droplet sequences thus enabling practical investigation microfluidic switching principles. We start by introducing a single DoD system and then we investigate a system that combines two DoD systems in order to generate header-payload pairs, leading to the truly first practical realization of microfluidic switching principles. Finally, we present possibilities for employing microfluidic networks as a promising platform for fast and flexible waterborne pathogen screening.

II. Droplet-on-Demand

The proposed DoD system utilizes a simple T-junction geometry and applies a series of positive pulses on one phase (dispersed phase), in order to generate droplets, while maintaining the second (continuous) phase phase at constant input pressure, as shown on Fig. 1. As the method relies on the control of only one phase, it offers high degree of stability, simplicity and reduces the need for synchronization between the two input channels [4].

The working principle of the proposed DoD system relies on the system toggling between two pressure states: equilibrium state, during which no droplets are generated, and the pulsing state, where equilibrium is overcome and during which the droplet generation takes place. By controlling the duration of the applied pulse, it is possible to control the size/volume of the generated droplet– a key feature in realizing DbS encoding mechanism. Moreover, by controlling the time period between the two successive pulses, it is possible to control the distance between two droplets thus enabling a basic working principle of DbD encoding.

A. Header-Payload Realization

In order to generate header-payload droplets pairs, i.e. to achieve DbD and DbS switching, it is possible to connect the two DoD systems on a single channel, as shown on Fig. 1. One DoD serves as a generator for payload droplets,

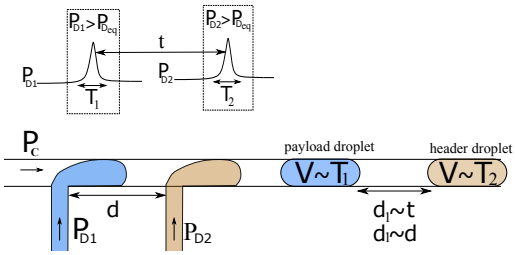

Fig. 1. Illustration of caseded DoD system for generating payload-header droplets

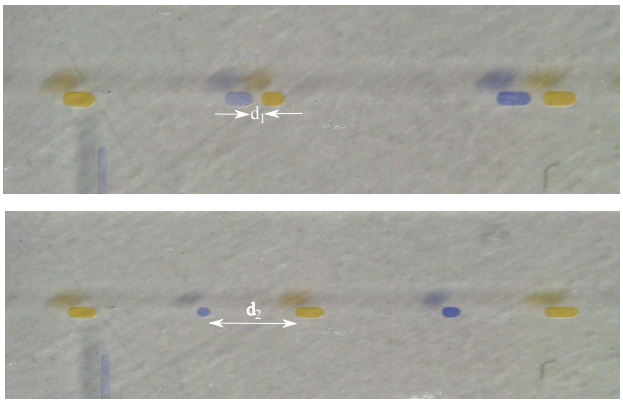

Fig. 2. Practical realization of header-payload droplet generation usind DbD encoding mechanism. The distance between the droplets was dynamically changed from d_1 to d_2 using the DoD system.

while the second DoD system generates header droplets. By synchronizing the two DoD systems, encoding of arbitrary information can be achieved simply by adjusting the pulsing parameters of the connected DoD systems.

III. Practical Realization

A. Materials and Methods

The proposed system is fabricated using a fast and simple fabricating method that employs laser cutting to engrave the geometries into the PMMA (Polymethyl methacrylate) material. The final chip was assembled from PMMA sheets using a hot press and ethanol. We have used a pressure controller (Elveflow®, OB1MK3) to induce pressure to the continuous and dispersed phase. Moreover, the pressure controller is able to apply a sequence of pulses either through the Elveflow® Smart Interface or by using the provided Matlab libraries. For the evaluation of the the DoD system (droplet size and distance) we used a microscope together with an integrated high-speed camera.

B. Experimental Results

The practical realization of the proposed system is shown on Fig. 2. As it can be seen, using two cascaded DoD systems, header-payload droplet pairs are generated. The distance between the droplets, as well as the droplet size, can be dynamically changed and programmed by simply modifying the parameters of the applied pressure pulses, thus enabling the DbD or DbS switching principles.

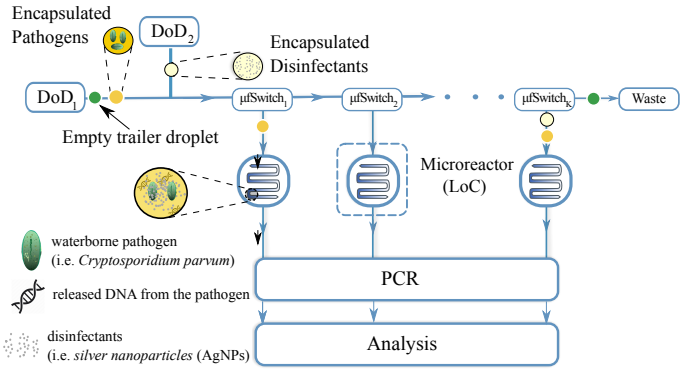

Fig. 3. Fast and flexible pathogen screening using microfluidic networks

IV. Envisioned Application

Sine microfluidic networks offer high degree of flexibility and parallelism, they are a promising platform for various biomedical applications (e.g. fast and flexible waterborne pathogen screening, as shown in Fig. 3). The network consists of a cascaded DoD systems and multiple LoC devices, interconnected through microfluidic switches. Such platform provides unique means of investigating the robustness of waterborne pathogens, which cannot be detected or deactivated using commercial water purification systems. Employing microuidic networks, such pathogens can be tested for a number of disinfectants in a short time on a single microuidic device.

V. Conclusion

We have introduced a DoD system that enables, for the first time, a practical realization of previously proposed microfluidic switching principles. We have presented practical validation of the proposed system by dynamically generating header-payload pairs of arbitrary distances and sizes therefore achieving DbD and DbS switching. Finally, we have introduced envisioned application that aims to employ microfluidic network as promising tool for investigating waterborne pathogens.

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