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A micro-controller based approach for digital microfluidic sensors

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Abstract

This work is oriented towards the study of digital microfluidic (DMF) devices. A DMF device is a liquid-droplets-handling platform with varied applications in the fields of medical diagnostics, drug discovery, chemical analysis, environmental monitoring, and basic scientific research. These operations can be performed in a rapid, low-cost, portable, and reliable environment using DMF devices. Two of the important elements of DMF devices are electro-wetting on dielectric phenomenon and hydrophobicity. Under an applied voltage of either AC or DC, the electro-wetting effect induces a reduction in the contact angle of the droplet with the hydrophobic surface. This enables manipulation of motion and position of droplets on the hydrophobic surface. In this work, the actuation of droplets on an open DMF device with a single array of electrodes is carried out. The fabrication of DMF plate is carried out on a copper covered plate by patterning using black tapes and etching using etchants. The circuit is arranged using PCB, jumper wires, 8-channel relay, 9V battery, ac-power regulator and a microcontroller (Arduino/Genuino UNO).

***Keywords**: Micro-controller, Sensors, Digital mircofluidics, Electrowetting, Fabrication, Arduino*
***Mathematics Subject Classification 2010:** 9404*

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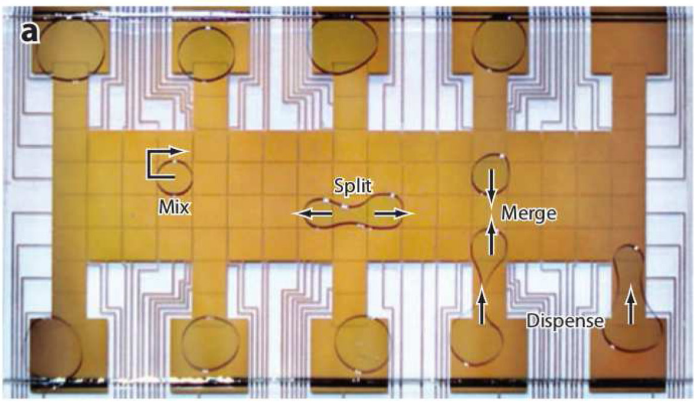
1. Introduction

Digital microfluidics (DMF) is a technology that makes manipulation of liquid droplets on an array of electrodes possible. These electrodes are covered with a dielectric and hydrophobic substance. In this technology, unlike channel-based microfluidic devices which uses channels, pumps, valves, and mechanical mixers, each droplets having the volume range from picolitre to microlitre are individually controlled using the electrodes on a substrate. The droplets can be made to mix, split, merge, and dispense from their reservoirs. DMF platform is highly reconfigurable,



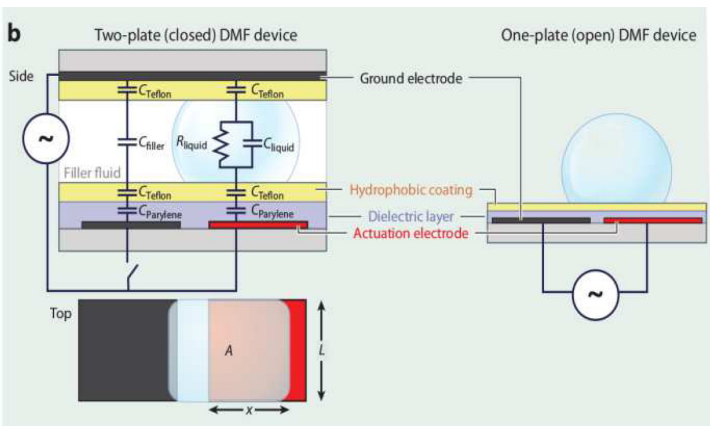


Figure 1

An overview of the droplet actuation platform of DMF device [1], (b) Lateral view of Two-plate (closed) DMF device and One-plate (open) DMF device [1].

programmable, and reusable. Moreover, it consumes reagents in lower quantities and can be integrated with other forms of technology [1].

2. Types of DMF

There are two types of DMF devices. One is the single plate (open) device and the other is two-plate (closed) device. In the single plate device, the droplet, which is usually polarizable or conductive (in both the cases), is placed on a substrate with arrays of actuation and ground electrodes.

In the two-plate device, the droplet is placed in between two substrates (top plate and bottom plate). The top-plate is the ground electrode. It is covered with transparent conductive layer (ITO). The bottom plate has arrays of actuation electrodes. Both types have an insulating layer (dielectric layer) coating the bottom-plate and hydrophobic layer covering on all the surfaces [2][3].

3. Theory of Digital Microfluidics

The operating principles of both open and closed DMF devices are similar. They function on the same principle which is electro-wetting on dielectrics. The closed DMF device operates in air or with other filler media which is usually silicone oil. The filler media is responsible for reduction of the voltage required for droplet movement. Also, the closed device makes a range of operations such as dispensing, moving, splitting, and merging of the droplet possible [1]- [4].

The open DMF devices are not capable of splitting the droplet and dispensing from the reservoirs. They are only suited for applications such as preparation and recovery of analytes are carried out [1] - [4].

4. Electrowetting on Dielectric and Droplet actuation

Electro-wetting-on-dielectric exploits the principle of regulating the interfacial tension between a liquid and an electrode by application of electrical potential [5]. The electrodes are covered with a dielectric layer and then with a hydrophobic layer. An imbalance of interfacial tension is generated due to the electric field that is passing through the dielectric layer. This imbalance of interfacial tension, which is due to applied electric field to only one part of the droplet, produces a difference in contact angle between two sides of the droplet. This creates a pressure gradient in the

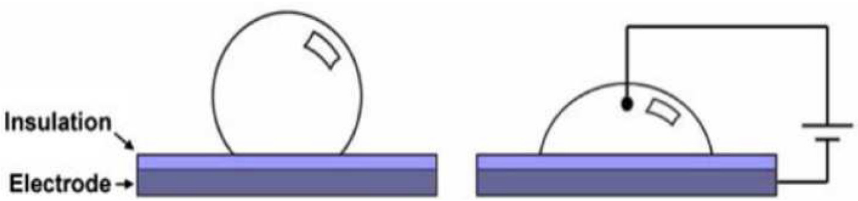


Figure 2

Depiction of droplet configuration on the electrode on electro-wetting by applying voltage to the electrode [9]

droplet and makes it to move towards the activated electrode [1], [2], [6], [7], [8].

Using thermodynamic approach, the Lippmann-Young equation gives the relation between the static contact angles with and without applied voltage i.e. θ, θ_0 respectively, the relative permittivity of the dielectric ε_r, the permittivity of free space ε_0, the applied voltage V, the filler media surface tension γ, and the dielectric thickness d.

$$cos\theta = cos\theta_0 + \frac{\varepsilon_0 \varepsilon_r V^2}{2\gamma d} \tag{1}$$

The force that is used to actuate the droplet is given by the following equation. The relation shows dependence of actuation force ($F_{actuation}$) on the capacitance per unit area (c), width of the electrode (L) and actuation voltage (V).

$$\mathrm{F}_{\mathrm{actuation}} = 1/2 \ LcV^2 \tag{2}$$

5. Threshold Voltage and Capacitive Effects in the System

At lower frequency, AC actuation has the lowest actuation voltage. This is due to time varying force components which lead to overcome sticking effects due to electro-wetting. But when the frequency increases the DC actuation has lower threshold voltage [7].

DC actuation has a downside due to the hysteresis. This is caused by the polarization of the insulator material. This polarization produces the increase of wetting of the droplet and hence leads to increase in the capacitance. This hysteresis does not occur in AC actuation. It is due to the quick switching of polarities and the dipoles do not have time to be polarized in a certain alignment [7].

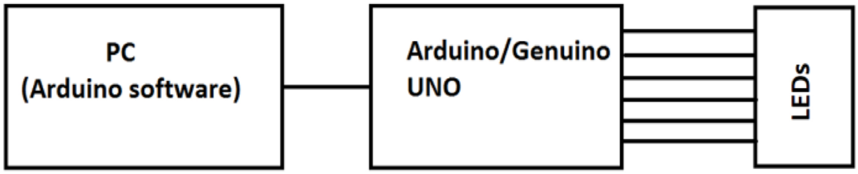


Figure 3

Block diagram of the system assembled to test the code written for the Arduino (Control Board)

6. Design and Fabrication

A DMF device has four main components. They are a hydrophobic layer, a dielectric layer, electrodes and a substrate.

In the open-plate DMF platform, the design for bottom plate is just the same as that of the closed-plate. But the continuous ground top-plate is removed. The actuation electrode and the ground electrode are adjacent to each other and continuous switching between the two adjacent electrodes takes place to actuate the droplet. These electrodes in both the cases have traces attached to them, which are connected to contact pads for the application of voltages on the electrodes

Printed circuit boards are more favoured in making the DMF devices. It is due to their convenient batch production and low cost [1], [2]. Metals (e.g., Cr, Al, Au, Cu) or other materials which are conductive (e.g., ITO, doped poly silicon) are used to make the electrodes.

The insulating dielectric layer (parylene, poly dimethyl siloxane) is used to cover the electrodes. This dielectric layer helps in the creation of charges or field gradients. The dielectric layer can be formed using many techniques. Some of the techniques are vapour deposition, thermal growth and spin-coating [10], [11].

The tracers are soldered with wires at the ends to provide contact leads. The microcontroller (Arduino/Genuino UNO) is connected to the 8-channel relay through jumper wires, AC-power regulator and a PCB.

7. Results and Conclusion

A theoretical model for the actuation and manipulation of the droplets has been developed. Initially the contact angle of the droplet is large when no voltage is applied as the droplet reforms minimizing its surface energy.

When an electric field or potential is applied to the adjacent electrode, the contact angle becomes smaller on that side allowing for actuation of

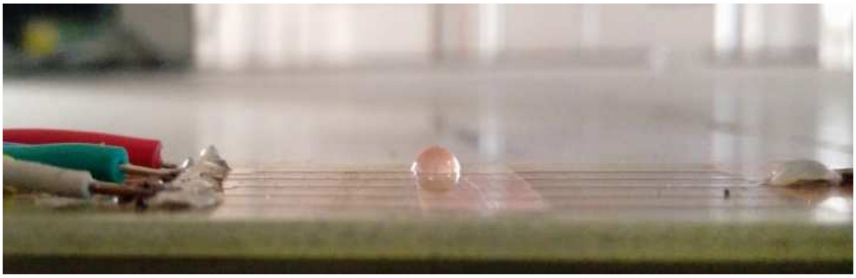


Figure 4

Droplet having large contact angle in the absence of electric field

droplets due to the surface energy gradient formed. Fig. 5 demonstrates a cross-sectional view of droplet, which is resting on surface.

The flow of droplet will occur whenever there will be unbalanced forces of tension acting along the line of contact (Or the asymmetry of the contact angles). θ_a and θ_b are the angle of contact on the two ends of droplet which are experiencing different surface energy and Lower γ_{SV} and higher γ_{SV} are lower and higher levels of energy of region surrounding the droplet[12].

This circuit design should be able to actuate the droplets across the electrodes of specific dimensions and pitch spacing of appropriate width. In Fig. 6(a) Blue electrodes- represent the ground electrodes Grey electrodes- represent the high voltage electrodes which are inactive Red electrode - represent the high voltage electrodes which are active. Here the ground or reference potential is being applied to the parallel electrodes [13].

Micro, nano or pico litre droplet can be actuated depending on the requirement of the system. According to this model the electrode

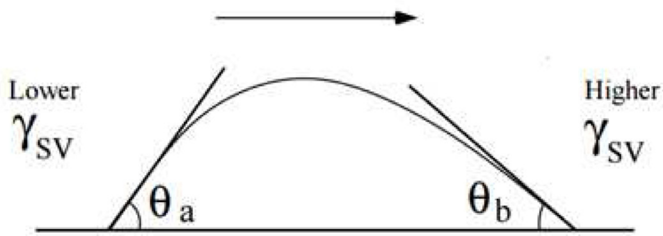


Figure 5

When the potential is applied on the adjacent electrode, the contact angles changes as shown [12]

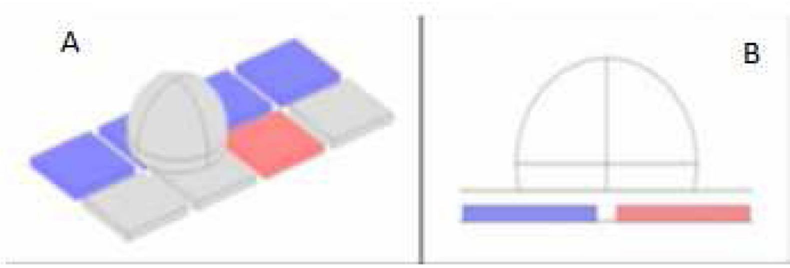


Figure 6

(a) 3D view of droplet, (b) Side view of droplet during actuation [11]

dimension is kept at 2mm X 2mm with pitch between electrodes no lesser than 75µm. The droplet size should be twice the size of a single electrode (4mm).

The feasibility of the program written has been confirmed using LEDs on a printed circuit board..

8. Conclusion and Future Prospects

The system for droplet actuation was created using an Arduino as a control board and micro-fabricated sensor module fabricated on PCB. Boards for high voltage switching and for point contacts with the chip were designed and manufactured. This system is functional and has been proven that it is capable of functioning as a biosensor, authors are planning to use it for environmental sensing applications, with emphasis on soil quality monitoring.

In future, we propose that DMF technology will be promising for point-of-care and field tests, with its obvious advantages like small sample volume, low power requirements and most importantly no special skill to operate. In current scenario, the use of DMF technology is limited, mainly due to the complicated fabrication process of DMF devices (compared with, for example, soft lithography for microchannels) and the lack of commercial instrumentation. With reference to the recent scientific developments in this area this situation will change with the development of mass production techniques and general-purpose DMF instruments. In summary, although DMF technology is still in its initial stage, it is continuously improving and has great potential to contribute significantly to applications in modern science, related to grass-root level problems.

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