Droplet Actuation Enhancement through Voltage Control and Hydrophobic Coating Selection

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Abstract: This paper presents a novel digital microfluidics platform that utilizes PCB substrate designed on Easy EDA software and is based on electrowetting on a dielectric (EWOD) phenomenon. For droplet actuation, the platform's performance was examined at different DC voltages ranging from 300V to 450V. The fabrication process was made simple and inexpensive by using readily available, low-cost ingredients including silicone oil, cooking oil, and olive oil with grafting tape as a dielectric layer. Compared to other oils used for droplet actuation, cooking oil yields the highest droplet velocity. Due to its affordable and easy-to-fabricate nature, our suggested digital microfluidics platform will be feasible for droplet actuation and can also be applied to medical diagnostic applications like DNA analysis and cell culture, as well as the detection of environmental pollutants.

***Keywords*:** Digital microfluidics (DMF); Electrowetting on dielectric (EWOD); Lab-on-a-chip

1. Introduction

Microfluidics focuses on researching and managing liquids at a very tiny size. Surface tension, diffusion, and rapid temperature changes are distinguishing features of fluids in microdomains compared to larger-scale fluids. An example of this is the electrowetting-on-dielectric (EWOD) device, which controls droplets on a dielectric surface by applying an electric field due to the difference in potential between electrodes [1]. EWOD has a wide range of applications in lab-on-a-chip settings, allowing for the control of complex processes necessary for laboratory operations. Digital microfluidics (DMF) may be set in two modes: open or closed configurations [2].

Microfluidics involves controlling and handling tiny volumes of liquids at a size close to the microscale. The liquids in this microdomain exhibit distinctive characteristics compared to larger-scale fluids, particularly in surface tension, diffusion, and rapid thermal relaxation [3]. Electrowetting on dielectric (EWOD) is the control of droplets on a dielectric surface by an electric field caused by a potential difference between electrodes. EWOD may be used in various lab-on-a-chip environments to carry out intricate operations necessary for laboratory tasks. This characteristic has resulted in its categorization as digital microfluidics (DMF), which has two distinct configurations: open and closed settings. This platform aims to facilitate the manipulation of very small droplets, speed up the movement of fluids, and provide guidelines for biological and chemical procedures [4]. Closed DMF devices are used for certain droplet activities because of their enhanced functionality and control in comparison to open platforms. DMF provides benefits such as reduced reagent use, enhanced heat transfer speed, and seamless compatibility with other analytical methods [5].

Colorimetric analysis of different analytes can also be done on a digital microfluidic platform. Several investigations have concentrated on channel-based microfluidic systems employing the Griess reaction for colorimetric nitrite assay [6], [7]. The approach using paper-based microfluidics might encounter challenges such as unpredictable fluid speed, limited mixing efficacy, and unfavorable color development [4], [5].

A different microfluidic method known as digital microfluidic (DMF) has arisen as a promising option for portable analytical systems, distinguished by its ability to manipulate fluids as discrete droplets ranging from picolitres to microliters DMF additionally provides significant versatility for integration with various analytical methods including Raman spectroscopy, colorimetry, electrochemistry, mass spectrometry, and electrochemiluminescence [8], [9]. This broadens its utility across analytical chemistry, chemical biology, environmental monitoring, and food safety applications [10]. Zhen Gu et al developed a palm-size DMF platform with integrated colorimetric analysis that detects nitrite concentrations in food samples [11], [12].

The present investigation employed a grafting tape dielectric layer in combination with silicon oil, cooking oil, and olive oil as hydrophobic layers [13], [14]. This combination enabled the efficient flow of droplets on a printed circuit board (PCB). The thin oil coating was essential in minimizing friction, allowing for easy movement of droplets on the PCB substrate. Utilizing two-dimensional digital microfluidics platforms offers dynamic adjustability and streamlined automation. DMF devices have the benefit of being able to handle small sample amounts, which leads to less reagent consumption and processing time [15], [16]. Full automation may be accomplished using Arduino without any human involvement [17], [18].

2. Material and methods

Distilled water was used in all experiments that were prepared in the Heat Engine Lab at GIKI. The designing of the PCBs was done on Easy EDA software and manufacturing of PCBs was done in Smart PCBs (Rawalpindi, Pakistan). The electrodes were square having dimensions of 2x2mm and the distance between two successive electrodes was 0.5mm. Grafting tape that was used as a dielectric medium was purchased from the online store (Daraz.pk), having a thickness of 0.03mm. Electrical equipment including a power supply having DC 1000V and current intensity of 1 milliampere was purchased from Qosain Scientific (Lahore, Pakistan). The oils having different viscosities (cooking oil, silicon oil, and olive oil) were purchased from the local market. The droplet movement and contact angles were analyzed with the help of ImageJ software.

3. Theoretical background

Electrowetting on dielectric (EWOD) is the alteration of a liquid's contact angle on a solid surface by applying an electric field via a thin dielectric layer. The theoretical equation for electrowetting behavior is obtained by considering the equilibrium of interfacial forces acting on a droplet on a dielectric surface. The primary equation used to calculate the equilibrium contact angle in electrowetting is the Young-Lippmann equation [19]:

$$cos(\theta_V) = \cos(\theta_0) + \frac{\epsilon_r \epsilon_0 V^2}{2\gamma d}$$

This equation depicts the correlation between the contact angle (θ) and the application of voltage. Here, ε_0 represents the permittivity of vacuum, ε_r indicates the relative permittivity of the material, and d represents the thickness of the dielectric layer. γ symbolizes the liquid's surface tension, while V symbolizes the applied DC voltage to an electrode. θ_0 reflects the droplet's initial contact angle before being subjected to the electric field [20].

4. Result and discussion

Figure 1 depicts the results and confirmation of droplet movement caused by applying a DC voltage. The results show that droplet motion begins at 220 volts. We tested several hydrophobic coatings and experimented with silicon oil, cooking oil, and olive oil to investigate other parameters affecting velocity. Examination of the velocity data shows that cooking oil outperforms silicon oil and olive oil, with droplet speeds of 8.5 mm/s at 450 V, compared to 6.9 mm/s and 1.4 mm/s, respectively. The percentage increase in velocity of droplets of cooking oil is almost 337.5% greater than silicone oil and almost 175% greater in case of olive oil. We have performed analogous studies while modifying the droplet volume. Droplets with smaller volumes provide improved actuation results at increased voltages. Moreover, the difference in droplet velocity becomes more noticeable at increased voltages for the three droplet volumes.

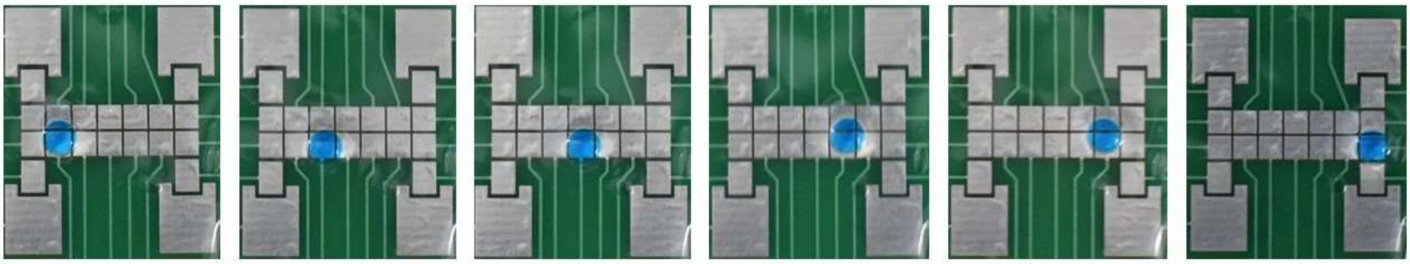

Figure 1: Droplet actuation in 6 frames.

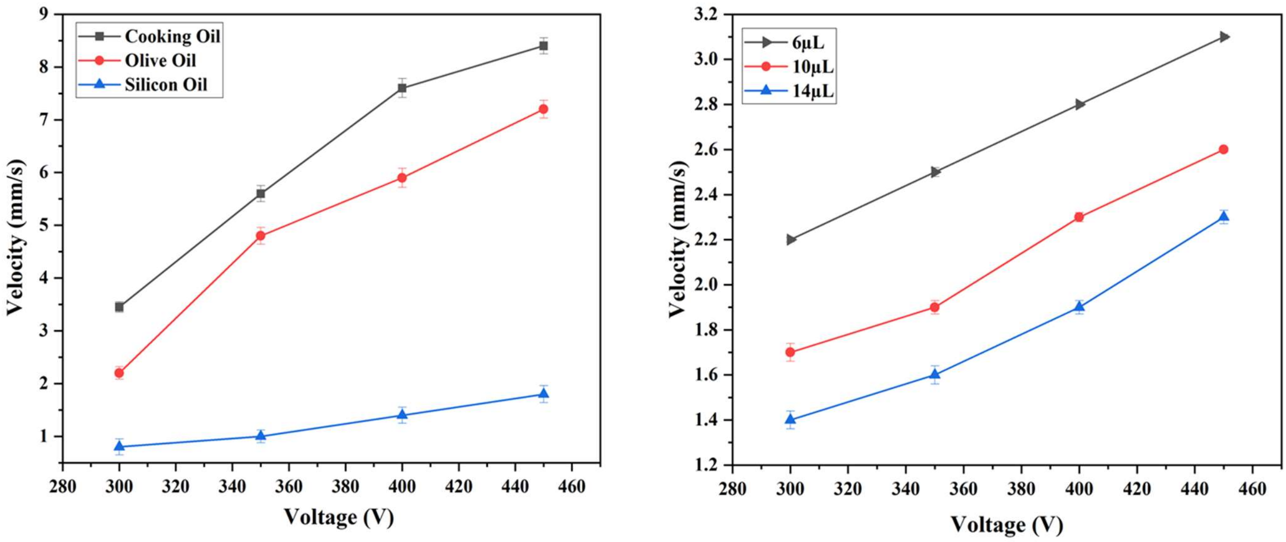

Figure 2: (a) Droplet speed against applied voltage for silicon, olive, and cooking oil; (b) Droplet speed with changing droplet volume.

The change in velocity is attributed to the viscosity differences of the oils used. Silicon oil had significantly greater viscosity than cooking oil and olive oil. Due to the decreased viscosity of cooking oil and olive oil, water droplets flow more easily across the electrodes compared to silicon oil and olive oil. The error bar in graph(a) and (b) depicts standard deviation of 3 different velocity results at a single voltage, 3 different values during experimentation at every working voltage was considered and average of all those values was calculated.

5. Conclusion

The research paper describes the creation of digital microfluidics (DMF) technology that uses electrowetting to accurately control microliter quantities of liquid samples. Experiments were carried out to evaluate the platform's performance at voltage ranges between 300 V and 450 V. The fabrication method has an open configuration design to improve flexibility and versatility. The platform was made cost-effective and suited for industrial use by using readily available materials including cooking oil, olive oil, silicon oil, and grafting tape. We successfully achieved our goals of designing a cost-effective platform, attaining linear actuation for accurate liquid manipulation, and combining numerous components into a functional system. The droplet velocities varied between 0.5 mm/s and 8.5 mm/s across various circumstances. The platform shows encouraging outcomes and possibilities for future progress in medical diagnostics, environmental monitoring, and chemical sensing applications.

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6. References

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