Supplementary Information for

Droplet Manipulation on An Adjustable Closed-Open Digital Microfluidic System Utilizing Asymmetric EWOD

Jingsong Xu [a], Xingcheng Wang[a], Qingyuan Huang[a] and Xiaodong He[a*]

[a]School of Information Science and Engineering, Lanzhou University, No. 222 Tianshui South Road, Lanzhou 730000, China.

[*]Authors to whom correspondence should be addressed: xdhe@lzu.edu.cn

When the side of the top plate has not been treated, the droplets will be adsorbed here, causing significant resistance that prevents the droplets from being transported smoothly between the two regions. As shown in Fig.S1.

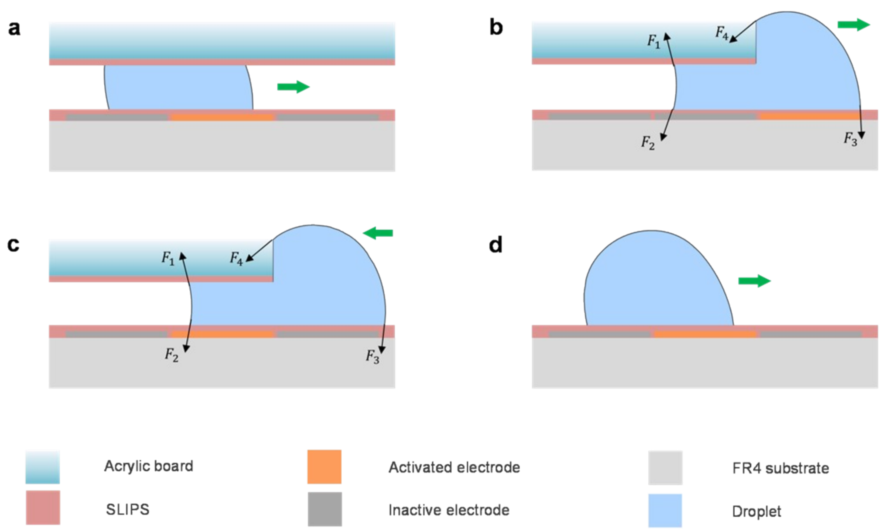

Figure S1. Droplet transport in different structures (not to scale). (a) in a closed region. (b) From a closed region to an open region. (c) From an open region back to the closed region. (d) in an open region. The edge of the top plate has not been improved.

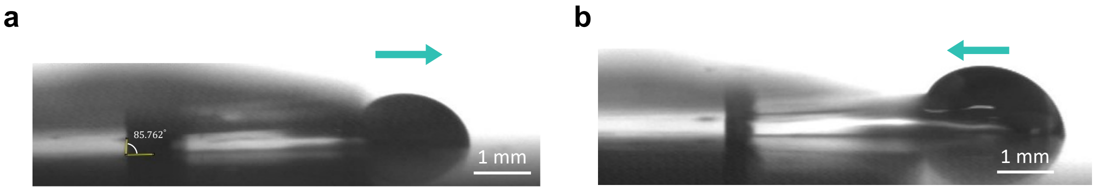

Figure S2. Side view of droplet moving at the closed-open boundary. (a) A snapshot of a droplet moving from the closed region to the open region. (b) A snapshot of a droplet moving from the open region to the closed region. Images were captured by a charge-coupled device (CCD) camera with a zoom lens.

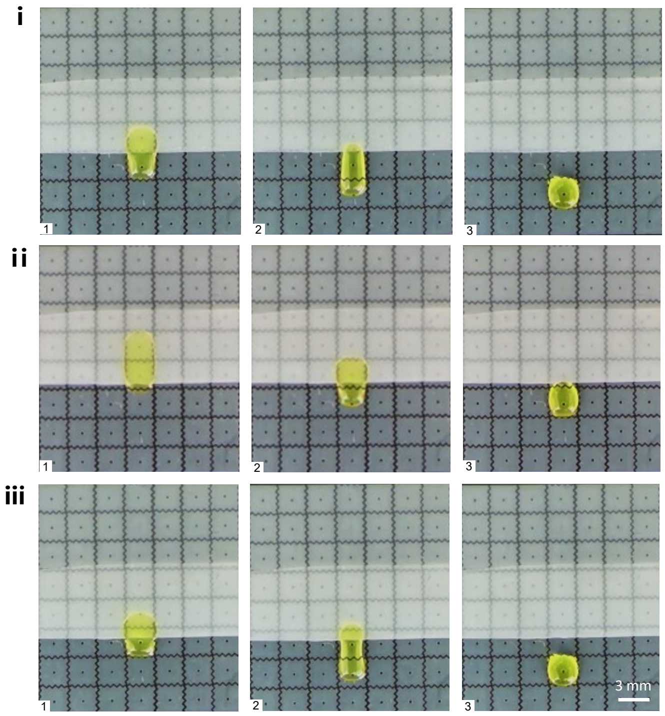

Figure S3. Transporting an 8 μL droplet across the closed-open boundary at different horizontal positions of the top plate. (i) The edge of the top plate is placed exactly above the center of the gap between the two electrodes. (ii) The top plate moves 0.75 mm (1/4 of the length of the electrode) towards the closed region. (iii) The top plate moves 0.75 mm towards the open region. All the droplets are driven under a DC voltage of 274 V. The plate spacing is 510 μm.

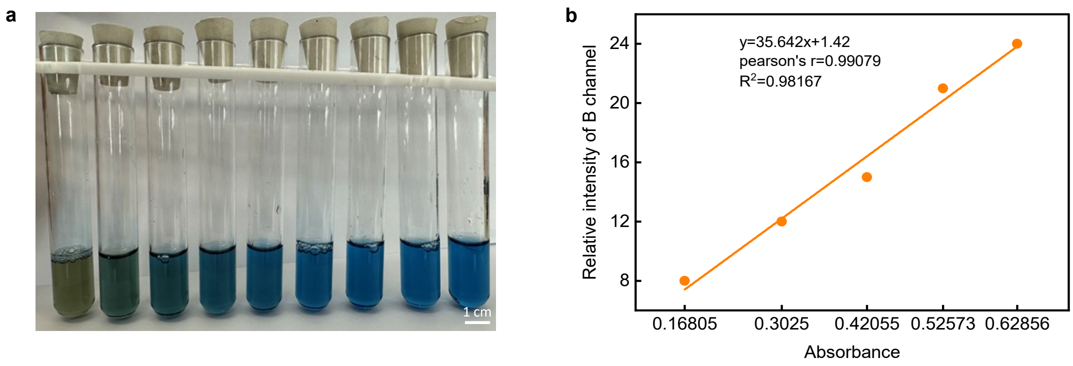

Figure S4. (a) At the concentration gradient of 0.01 g/L, the protein solutions of 0-0.08 g/L were mixed with Coomassie Brilliant Blue to establish a standard curve. (b) The correlation curve of absorbance and relative intensity of the B channel.

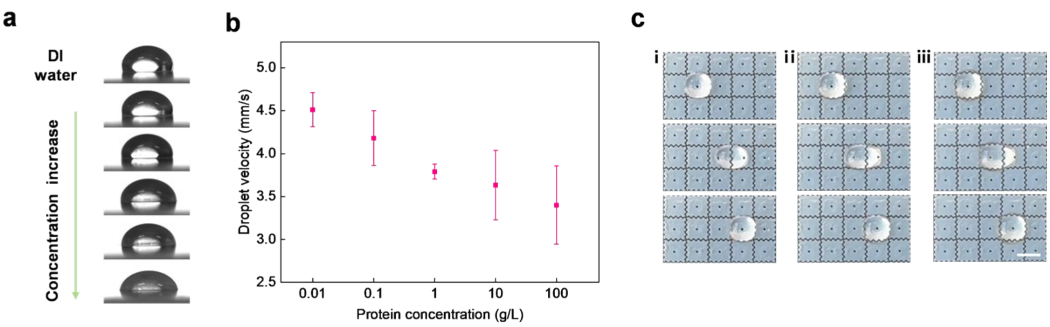

Figure S5. (a) Contact angles of protein droplets with different concentrations on the surface of SLIPS. The first droplet is DI water, and the concentration of the protein solution gradually increases from the second droplet, the concentrations are 0.01 g/L, 0.1 g/L, 1 g/L, 10 g/L, and 100 g/L, respectively. The volume of the droplet is ~10 μL. (b) Different protein concentrations and their transport speed on the open surface. The volume of each droplet is ~10 μL, and the driving voltage is 274 V. (c) Frame images of protein droplet transport at different concentrations, (i) 0.01 g/L, (ii) 1 g/L, (iii) 100 g/L. The droplet volume is ~10 μL, and the scale bar is 3 mm.

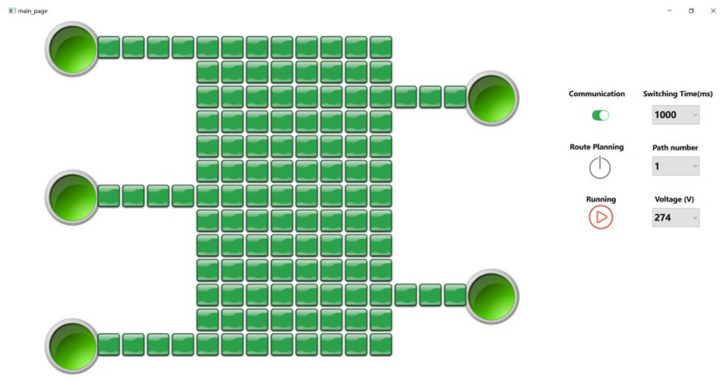

Figure S6. Graphical user interface (GUI) developed by Qt, including the functions of droplet path planning and real-time control, voltage regulation, and electrode switch interval regulation.

This graphical user interface (GUI) application is implemented based on the Qt 6.5 C++ development framework. The droplet control interface is mainly composed of square buttons (corresponding to the square electrodes of DMF chip), circular buttons (corresponding to the reservoirs of DMF chip), and other control function buttons. Each button returns a button address parameter to the slot function. By clicking on a button, it is determined whether the button is a square button or a circular button, and the piositions of the button are determined. In addition, the state of the buttons is modified by switching the background image.

The GUI provides several key functions, including basic droplet manipulation (transporting, dispensing, splitting, and merging), electrode switching time interval adjustment, and path planning. The droplet dispensing function involves changing the status of buttons at certain intervals according to the preset button address sequence. The serial communication module packages the sequenced addresses and then sends them to the microcontroller unit (MCU). In addition, the program can also perform real-time click manipulation of droplets. These manipulation functions of the droplet are achieved through interrupt communication with the MCU. When the path planning function is disabled, each clicked button sends an electrode address to the MCU, which receives an interrupt signal and converts the electrode address into the appropriate electrode control signal. Enabling the path planning function, the address of buttons clicked by the user will be temporarily stored in a vector in sequence. Once the user finishes the route planning and clicks the "Run" button, the communication module will package and send the data to the MCU. Then following the First In First Out (FIFO) principle, the button addresses are read at intervals, and the corresponding droplet manipulation (transporting, splitting, merging) and other functions are executed through the incoming electrode control signal until all electrode address in the vector are read. Furthermore, for multi-path planning, the button addresses clicked by users can be stored as multiple vectors based on the single-path planning, and the elements of multiple vectors can be read simultaneously to perform corresponding functions. Other control functions, such as voltage regulation and electrode switching time regulation, are also transmitted using the same communication method.

Regarding the communication module of the program, the GUI incorporates communication switches, voltage regulation, and the data transmission function for button addresses (electrode addresses). Based on the Qt 6.5 C++ QSerial library, instructions and data are sent to the MCU in hexadecimal format, which receives data through the UART protocol. The communication switch function operates based on the Qt signal slot mechanism, which controls the communication function by disconnecting and connecting the signal slot of the button addresses data transmission function. When a voltage regulation command is sent, it temporarily interrupts the MCU and waits for the transmission of the voltage regulation level parameter to the MCU. Similarly, when sending electrode control commands, the MCU is also temporarily interrupted and the status of all electrodes is sent to the MCU in hexadecimal format.

List of Videos:

Video S1 shows the GUI interface communicating with the DMF platform to manipulate droplets, including transporting, dispensing, merging, and splitting.

Video S2 shows the droplet dispensing at different plate spacing.

Video S3 shows the different strategies of droplet dispensing, the daughter droplets are dispensed on the third square electrode and fourth square electrodes, respectively.

Video S4 shows droplet manipulation in an open region, including the mixing of two droplets and the transportation of multiple droplets.

Video S5 shows four basic manipulations of droplets in a closed region.

Video S6 shows the transport of droplets of different volumes at the closed-open boundary.

Video S7 shows the back-and-forth transportation of droplets at the boundary when the top plate is in different horizontal and vertical positions.

Video S8 shows the multiple cycles of droplet transport back and forth at the boundary.