Design and Implementation of Intelligent Digital Microfluidics Systems

by

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Master of Science in Electrical and Computer Engineering

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Faculty of Science and Technology
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A thesis submitted in partial fulfillment of the requirements for the degree of

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Approved by ______________________________
Supervisor

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Abstract

DESIGN AND IMPLEMENTATION OF INTELLIGENT
DIGITAL MICROFLUIDICS SYSTEMS

by CHEN TIANLAN

Thesis Supervisor: Prof. Mak Pui In
Thesis Co-Supervisor: Prof. Vai Mang I
Master of Science in Electrical and Computer Engineering

The manageable electrowetting-on-dielectric (EWOD) behavior of microdroplets, under variable-charged surface electrodes, has inspired the development of digital microfluidic (DMF) systems for large-scale micro-reactors, which have underpinned a wide variety of chemical or biological applications in tiny droplet volumes.

Reliability, robustness and efficiency are still great challenges of DMF-based micro-reactors due to the co-existence of different sorts of chemical reagents and biological species. It is particularly true for those containing sticky constituents, and the various irregular sample-originated surface damages, adsorption, and aging effects of the insulation and hydrophobic materials of the DMF chip.

Firstly, this thesis presents the setup of DMF control system provides user-friendly operation, experimental repeatability, real-time multi-droplet actuation/sensing and upgradable human-control interface. Secondly, a wide variety of control-engaged droplet manageability is proposed and demonstrated through the operation of our DMF control system, which comprises: (i) rigid profiles ability of different droplet's hydrodynamics under a real-time trajectory track of droplet-derived capacitance, permitting accurate and autonomous multi-droplet positioning without visual setup and heavy image signal processing (ii) fuzzy-enhanced controllability saving up to 21% charging time when compared with the classical approach, enhancing the throughput, fidelity and lifetime of the DMF chip, (iii) expert manipulability of multi-droplet routings under countermeasure decisions in real time,

preventing droplet-to-droplet or task-to-task interference. Thirdly, a novel microdroplets control signal (nature discharge after pulse, NDAP) and cooperative electrode control (CE) are introduced and investigated, which enhance the droplet transportation independently of the composition of the droplet and therefore no calibration for each chemical solvent is required. ~26.8% lower RMS voltage and ~17.6% higher velocity are concurrently achieved under NDAP + CE, when compared to the classical way.

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GLOSSARY

C_i. Instant electrode capacitance

C_t. Targeted electrode capacitance

X_0. Dynamic droplet position

L. The electrode pitch

L_g. The gap between electrodes

V_{max}. The maximum velocity

T_{ref}. The reference charging time

D_x. Fuzzy inference engine input range

G_f. Fuzzy inference engine output rang

T_c. The fuzzy-enhanced electrode's compensation charge time

T_{total}. The total charging time

R_{thresh}. The threshold value

G_f. The derived defuzzification

$v_{droplet}$. The droplet velocity

t'_α. The initial high-level excitation

u_α. The peak value

u_{Low}. The voltage applied to the electrode in low-voltage duration

u_β. The initial voltage of low-voltage duration

τ. The *RC* time constant

t_{th1}. The cooperative charging timing

t_{th2}. The droplet arrived timing

t_α. The recharge pulse duration

th_1. The droplet arrived threshold

$\boldsymbol{th_2}$. The cooperative charging threshold

$\boldsymbol{C_b}$. The capacitance of blocking capacitor

$\boldsymbol{C_d}$. The equivalent capacitance of droplet

$\boldsymbol{V_{rms,discharge}}$. The RMS value of natural discharge duration

LIST OF ABBREVIATIONS

AC. Alternating Current

BSA. Bull Serum Albumin

CE. Cooperative Electrode

DC. Direct Current

DMF. Digital Microfluidics

DNA. Deoxyribonucleic Acid

EWOD. Electrowetting on Dielectric

FPGA. Field Programmable Gate Array

IC. Integrated Circuit

ITO. Indium Tin Oxide

IE. Individual Electrode

LOC. Lab on a Chip

μTAS. Micro Total Analysis Systems

NDAP. Natural Discharge after Pulse

PC. Personal Computer

PCB. Printed Circuit Board

PBS. Phosphate Buffered Saline

PMMA. Polymethyl Methacrylate

RMS. Root Mean Square