

**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  
University of Macau**



Design and Implementation of Intelligent Digital Microfluidics  
Systems

by

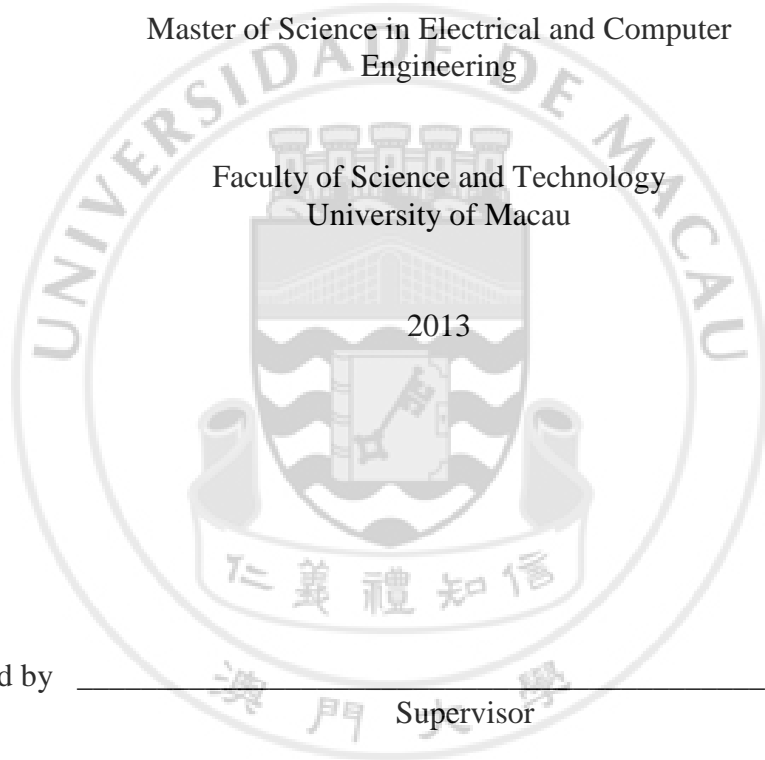
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A thesis submitted in partial fulfillment of the  
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Approved by \_\_\_\_\_ Supervisor

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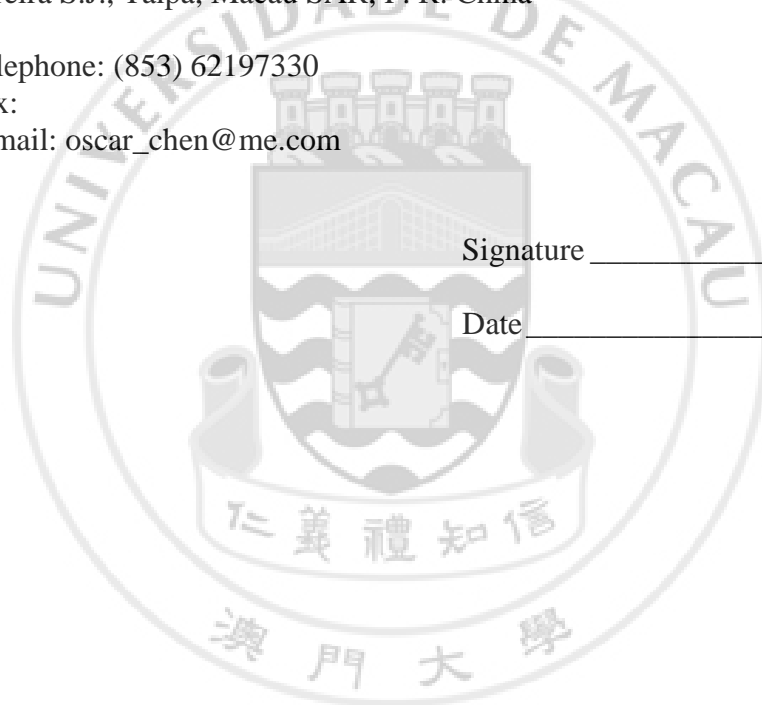
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Abstract

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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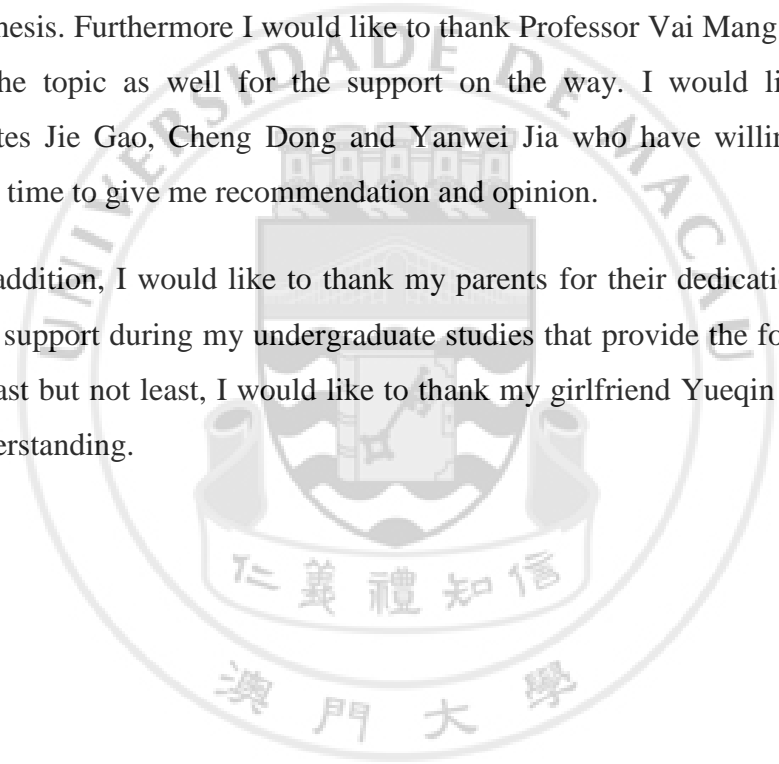
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## GLOSSARY

$C_i$ . 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

$T_{\text{ref}}$ . 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

$T_{\text{total}}$ . The total charging time

$R_{\text{thresh}}$ . The threshold value

$G_f$ . The derived defuzzification

$v_{\text{droplet}}$ . The droplet velocity

$t'_\alpha$ . The initial high-level excitation

$u_\alpha$ . The peak value

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

$u_\beta$ . The initial voltage of low-voltage duration

$\tau$ . The  $RC$  time constant

$t_{th1}$ . The cooperative charging timing

$t_{th2}$ . The droplet arrived timing

$t_\alpha$ . The recharge pulse duration

$th_1$ . The droplet arrived threshold

$th_2$ . The cooperative charging threshold

$C_b$ . The capacitance of blocking capacitor

$C_d$ . The equivalent capacitance of droplet

$V_{rms,discharge}$ . 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

