Proceedings of ICEGEE 2026 Symposium: AI-Based Medicine and Biological Data Analysis
DOI: 10.54254/2753-8818/2026.AU31805

The Development and Expectation of Microfluidic Driving and Controlling Technology

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Abstract. Due to its perfect performance and characteristics like high integration, high sensitivity and high throughput detection ability, microfluidics technology attracts much attention from researchers in related areas, such as DMF and LOC. The driving and controlling technology play vital roles for development of microfluidics chips and system integration. The driving technology by various physics fields and innovative DMF controlling technology are introduced in detail to show the progress of this technology. The microfluidics technology has shown broad application in many fields, such as pharmaceutical engineering, chemical analysis, nanometerscale fabrication. However, the current technology still faces the problems of high driving voltage, a small number of electrode arrays, and low efficiency of system control. It restricts the development of microfluidics technology. As an emerging field, microfluidic technology is developing rapidly and gradually permeating various industries. With continuous technological advancements and increasing market demand, the future prospects of the microfluidics industry are broad. Through policy support and technological innovation, microfluidic technology will play an increasingly important role in areas such as healthcare and environmental monitoring.

Keywords: Microfluidic driving technology, microfluidic controlling technology, digital microfluidic

1. Introduction.

Compared to traditional fluid research methods, microfluidic chip systems have many advantages, such as relatively low production costs, low sample consumption, small size for easy integration, and faster reaction speeds. As a result, it attracts many researchers's attention. With these advantages, microfluidic chip systems have broad application prospects in many key areas, including analytical chemistry, cell biology, organic-inorganic composites, agriculture, and textiles [1]. Especially when the period of global pandemic of the novel coronavirus disease (SARS-CoV-2) has been spreaded , point-of-care testing (POCT) technologies, represented by microfluidic systems, have received unprecedented attention and make some achievements in the field of home self-testing [2]. Microfluidic technology is an emerging interdisciplinary technology aimed at precisely controlling or processing tiny volumes of fluid ranging from microliters (μL, $10^{\wedge-6}$ L) to picoliters (pL, $10^{\wedge-12}$ L) . Within microchamber chips on the micrometer (μm) scale, it goes through some

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processing such as delivery, mixing, and separation. This technology provides the research field with advantages of integration, miniaturization, and automation. In 1990, Manz et al. first proposed the concept of microfluidic technology. Microfluidic chips integrate multiple basic maneuverable units involved in conventional chemistry and biology into chips. It only spans a few square centimeters. Networks are formed through microscale channels (microchannels), and controlled how fluid flows throughout the system. It enables the detection functions of traditional chemical or biological laboratories. Because of that, it earned the name "Lab-on-a-Chip" (LOC). In the compouding procedure of microfluidic chips, polymer materials have become the favoured synthetic materials due to their wide range of applications, variety, and ease of processing [3].

To show about the the microfluidic driving and controlling technology, some cases are illustrated with the brief introduction of working principles. In this essay ,driving technology is sorted by some kinds, such as capillary driven technology, surface tension-driven technology, micropump technology, pressure pump driven technology. With the development of microfluidic technology, Current microfluidic driving technologies can be divided into two categories: passive and active. Passive driving technology refers to a passive method. That means it does not require external power. At the same time, fluid flow can be achieved solely through the structure and design of the microfluidic chip itself, such as driven by capillary action or gravity. Active driving technology refers to a driving method that requires external power to drive the fluid, such as using positive and negative pressure, electromagnetic force, or centrifugal force to achieve precise driving [2]. As for controllment, digital microfluidics is a inovative technology by using arrays to control the condition of microvalves. This essay introduces some driving technology and a inovative controling technology and show out their respective advantages and disadvantages.

2. The development of microfluidics

2.1. Capillary-driven technology

Capillary-driven technology uses the capillary phenomenon in microchannels to drive microfluidics without an external power source [2]. In microchannels, due to the surface tension of the liquid and the wetting effect at the liquid-solid interface, capillary phenomena occur, meaning the liquid can spontaneously flow without external forces [4]. Xiao hua, Fang research and develop a Quantitative Plasma Separation Device and Protein Fluorescence Detection Chip. Then, he test the performance of chips integrated by two devices. The quantitative plasma separation method used by Fang Xiaohua achieves quantitative separation under various gradients, with small quantitative errors. It also has the advantages of a simple structure and easy integration with microfluidic chips. On one-step whole blood testing chips, it fills the current gap in self-driven whole blood testing chips and laying a foundation for future research [4]. The plasma separated using the separation chip still experiences some protein loss. Further research is needed to confirm the causes of this protein loss, such as adsorption by the pores of the filter membrane or adsorption on the surface of the separation chip [4]. This research explored a new way to detect plasma. It optimize the detecting way to a more automated one.

2.2. Gravity-driven technology

Gravity-driven technology only utilizes the gravitational force of the microfluidics itself to drive microfluidic flow [2]. The system features a simple structure, easy operation, high integration, low processing cost, and ease of widespread adoption [5]. Yan zhen, Huang adopted chip processing

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method of Lithography and wet etching to achieve goals. After that, she set out a Electronic Circuit Testing System to form whole microfluidic system. This experimental system utilizes gravity to drive liquid flow and introduces samples. They used a gate injection method, aiming to simplify the system's structure and operation, and improve its miniaturization and integration. The system uses an extension tube at the chip outlet to flexibly adjust the hydrostatic pressure difference between various reservoirs. In that case,the driving force is changed. At the same time, it also uses horizontally placed large-diameter reagent and waste tanks. In addition, it can maintain a relatively constant hydrostatic pressure in the channel for a longer period of time. One limitation of these gravity driven systems is that they are greatly affected by changes in fluid temperature and viscosity [5]. The innovation of this study lies in its design for regulating hydrostatic pressure to improve its accuracy.

2.3. Micropump driven technology

With the rapid development of microfluidic systems, researchers' demand for microfluidic automation and precise control continues to grow. At the same time, the advancement of Micro Electro Mechanical Systems (MEMS) has laid a solid foundation to advance micro pump technology. Electromagnetic micro pumps use magnetic fields to drive the movement of magnetic conductors to drive microfluidic flow [2]. Li and Wang have developed an intelligent electromagnetic-driven microfluidic chip, combined with the G-quadruplex DNAzyme biocatalytic platform, for dual-mode fluorescence/colorimetric detection of TC [6]. This method uses M-CDs Apt as a sensing probe. Based on the dynamic quenching effect of IFE and TC on the probe, fluorescence changes are generated to achieve fluorescence detection of TC. The probe combines with hemin to form a catalytically active hemin-G tetrastranded DNA enzyme. The enzyme catalyzes the color change of TMB and achieves visual detection of TC. In addition, intelligent control of magnetic materials has been achieved through self-developed programs. It improves the automation level of the detection process, reduces human errors, and enhances reliability. However, detecting multiple antibiotics in tilapia samples simultaneously remains challenging. Future research should further expand the capabilities of detection platforms, continue to optimize microfluidic chip design, and develop more efficient multi-target detection systems [6]. The breakthrough lies in its use of intelligent control of materials to achieve self-development.

2.4. Digital microfluidics

As an emerging droplet manipulation technology, digital microfluidics have attracted the attention of many research institutions and scholars due to their advantages such as low experimental reagent usage, simple equipment design, and fast and timely reaction detection [7]. A method for manufacturing a closed PCB EWOD device has been proposed, and researchers have carried out a series of studies. Among them, electrodes of different shapes were designed (such as crescent, fork, rectangular, notched, and serrated edges), and the results showed that serrated edges could drive droplets more effectively. However, the device can only drive 2.5 μ L droplets at high driving voltages, and the limited number of electrodes limits its application in large-scale operations. Therefore, the current main problems are the need for excessive external voltage, a small number of array electrodes, difficulty in accurately controlling droplet volume, and low droplet driving efficiency [7]. There is also a case study about digital microfluidics. This study is based on digital microfluidic technology using dielectric wetting, with a focus on developing digital microfluidic chips to create a PET radiotracer synthesis system. Its aim is to process simple radionuclide labeling

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reactions. By using a single chip with multiple channels that can be operated simultaneously, multiple conditions can be tested simultaneously, further highlighting the advantages and potential applications of digital microfluidic technology in PET radioactive tracer synthesis. Additionally, a well-established PET probe (18F-AlF-NOTA-octreotide) was used as the experimental target to synthesize and analyze the corresponding probe parameters. This gives a new way for synthesizing clinical PET tracers, potentially addressing the challenges of high costs, complex synthesis conditions, and the large size of equipment associated with clinical PET tracers. This study is based on the medium electrowetting-on-dielectric (EWOD) hybrid microreaction technology, using a simulation model constructed through numerical calculations to assist in the optimization of microfluidic chip design. This technology enables single-unit operations (transportation, heating, mixing, and solvent exchange) on organic or aqueous droplets, and, when combined with micro-scale, micro-dose reactions on the chip, allows for simultaneous multi-condition screening in a short time. It provides a new method to solve the problems of high cost, complex synthesis conditions, and large equipment size of clinical PET tracers [8]. This study has its limitations. It only calculated the quarter symmetric model without considering boundary effects. Future work can optimize computational conditions, expand models, and include more physical factors to improve the accuracy and applicability of microfluidic technology [8]. The important part of this study is the short-term multi-state monitoring.

3. Challenges of microfluidics

As for its processing procedure, it is complicated of controllment, integration, and design on chips. It still remains the problem of technology to drive micropumps as well as control microwaves on a microscale. Though it is easy to make PDMS materials, its characteristics of worsened solvent resistance restrict its industrial production. When chips are processing samples, it still faces the physical challenges such as filtration, enrichment, and bubble removal.

4. Application of microfluidics

Microfluidic technology has shown great application potential in the construction and efficacy evaluation of nanomedicines. By precisely controlling the preparation process and optimizing drug delivery systems, microfluidic technology improves the efficiency and quality of nanomedicine production [9]. The advantages of droplet microfluidic systems in chemical synthesis have also been widely recognized. This system can create and homogenize solute and temperature gradients in a short period of time, while avoiding interactions between surfaces and molecules, thereby allowing reaction conditions to be controlled in a way that is difficult to achieve on a macroscopic scale [10].

5. Broad view of microfluidics

Based on various kinds of driving technology, the new technology called DMF show its broad view and application to precisely and intellectually controll the fluid by its working principles. It realized the miniaturization, integration and high throughput of equipment. It transform processing on hand to "Lab on chips". Its scientific achievement will contibute to many key areas in our life, such as disease dianosis, drug development, environment protection, food safety, synthetic biology. In the future, with further integrated by AI and new material technology, this technology is going to be more intellectual and automated [10].

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6. Conclusion

This essay overviews the typical driving technology and a popular controlling technology as well as conclude their own pros and cons. By its high efficiency and accuracy, this technology can reduce the consumption of energy and materials [10]. By integration and innovation between microfluids and other subjects, the development of microfluids on different areas such like biomedicine, agriculture will be further advanced. It will contribute to the solutions on the problems of health, energy, environment.

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