Chapter 8
Advanced Strategy for Droplet Routing in Digital Microfluidic Biochips Using ACO

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ABSTRACT

Significant researches are going on for high performance droplet routing in Digital Microfluidic Biochip (DMFB). This chapter elaborates an ant colony optimization based droplet routing technique for high performance design in DMFB. The method is divided into two phases. (1) In the first phase, two dedicated ants generated from each source of the droplets traverse the rectilinear path between the source-target pairs and deposit pheromone to construct rectangular bounding box. Initial bounding box helps in restricted ant movements in the next phase. (2) In the second phase, real routing path is generated. Detour and stalling phenomena are incurred to resolve routing conflict. The method has explored both single ant and multiple ant systems to address detours from the conflicting zone in search for the best possible route towards destination. The method has been simulated on several existing benchmarks and comparative results are quite encouraging.

INTRODUCTION

Digital microfluidic biochip (DMFB) revolutionizes the medical diagnosis process rendering multiple tasks executed on a single chip. Microfluidic based biochips are presently aiding different pathological experimentations and many biochemical laboratory procedures due to their advantages of automation, cost diminution, portability, and competence (Pamula, Srinivasan & Fair, 2004). Growing trends of demand and need for incorporation of multiple-functionality makes the design process complex and costly for digital microfluidic biochip. It has laid a scope for optimization in computer aided design and test before on-chip fabrication. In present days it is a thriving field for researchers and they are exploring

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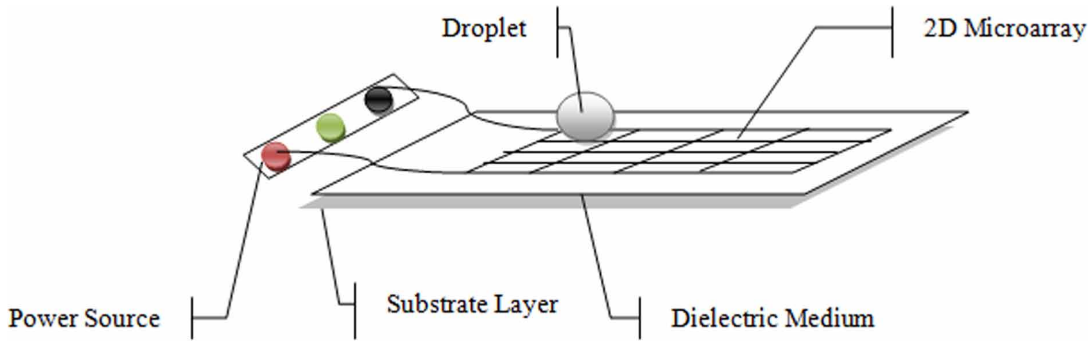
Figure 1. Schematic Layout of DMFB



different design aspects to deliver a fully customized biochip (Fair, Su & Chakrabarty, 2006). Digital microfluidic biochip is a small test cites which comprises an array of electrodes sandwiched between two parallel plates. The droplets are manipulated (stored, transported, mixed or reacted) over the electrodes by changing the voltage of two adjacent electrodes and droplets are transported from one electrode to the next by electro-wetting on dielectric (EWOD) technique (Pamula et al., 2004) (Figure 1). Droplet routing is one of the fundamental issues in design of DMFB and major variants in this field are direct addressing mode, cross-referencing mode and pin-constrained droplet routing and design (Chakrabarty, 2010). Mostly, geometry level synthesis of biochip design involves droplet routing, and all the problems are formulated as complex optimization problems, which are NP hard in nature (Su, Ozev & Chakrabarty, 2004; De Micheli, 1994).

Researchers and CAD developers propose several models to solve those optimization problems. Mostly explored field is integer linear program (ILP) solver. ILP solver is a deterministic process which can provide solutions even for hard bioassay protocols. Meta heuristic search procedures are modern in their nature and are merely deployed in the field of biochip design automation. Some works exploring meta-heuristic techniques, named tabu search (TS) and simulated annealing (SA), are found in (Paul, Elena & Madsen, 2009; Xiao & Young, 2010) respectively. Droplet routing in digital microfluidic biochip can be modeled as a combinatorial optimization (CO) problem, and aim of this work is to solve the CO problem using a Meta heuristic strategy named ant colony optimization (ACO). ACO is basically a probabilistic model that uses stochastic search procedure to generate solution (Chun, Huang & Hao, 2009).

In this chapter a new ACO paradigm has been proposed to address droplet routing problem in DMFB. The droplet routing problem is a constrained optimization problem, where constraints are governed by the input bioassay protocol and resource utilization (mainly electrode usage and droplet routing completion time) constraints. The proposed method is divided into phases. Given a search space, (1) in the first phase, a restricted movement zone for the ants are constructed by computing rectangular bounding box between the source target pairs of all the droplets. (2) Next, an adaptive local search technique is employed by the real ants to mark the routing paths for all the droplets. Pheromone deposited by the real ants on their way towards target contains the information of elapsed routing time and remaining Manhattan distance (rectilinear distance) from the target location. Consecutive ants use those pre-deposited pheromone during search for their routing path towards the predefined target location with the shortest route and in turn optimizes the resource utilization. Basic objective in this optimization process is to minimize electrode utilization and routing completion time for all the droplets.

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