Memristor-based linear and quadratic programs solver

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Optimization solver has wide applications in chemical engineering, legged robotics, and autonomous driving. One of the key challenges is solving a linear or quadratic programming optimization problem in real-time. This issue limits the application of the optimization technique significantly since most applications in robotics require real-time control signal output. Over several decades, many researchers tried to address this issue via different approaches. The analog circuit solving optimization circuit came out as a unique solution for this problem, since it computes in the analog domain and significantly reduces the computation time. And this analog circuit can be designed as a general optimization solver with memristors (Figure 1).

Figure 2 shows the circuit architecture we proposed to build. The memristor crossbar-based analog optimization solver contains memristor crossbar circuits, optimization circuits, memristor tuning circuits, reading circuits, and control circuits. The optimization computation is conducted by the optimization circuit, memristor crossbar circuits, and the reading circuit directly. The optimization circuit (Figure 2) contains constrained circuits and cost circuits. The basic idea is to map a constrained LP/QP problem to the solver circuit, and when the stable state of the circuit is reach, the voltages on each columns represent the solution to the problem. The rigorous proof of the circuit was provided in previous research [1]. The memristor tuning circuit and control circuit are used for tuning the memristor crossbar array to the desired parameters so that the optimization problem can be mapped to the optimization circuit.

Here we choose linear programming and quadratic programming problem with small sizes as a demonstration. In a small size problem testing, the linear programming problem can be mapped to a 4×7 crossbar structure and the quadratic programming problem can be mapped to a 6×8 crossbar structure. Both the circuit simulation (Figure 3) and the digital algorithm are consistent, which demonstrates the feasibility of the analog optimization solver (Table 1). Since the mathematical proof is the same, the dimension of the optimization problem can be easily scaled up. Both equality constraint and inequality constraint conditions are used in the optimization problem formulation and circuit simulation. It can also be observed that the accuracy of the analog computing result is within 0.67%. Therefore, the result shows that the memristor-based optimization solver yields high accuracy with reconfigurability. The experimental results will be presented in the conference.

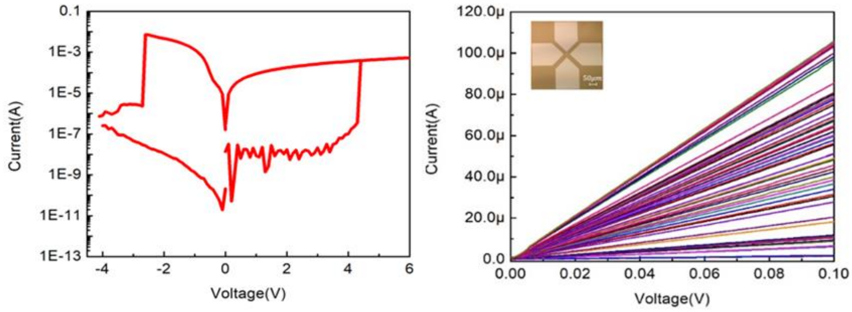

Figure 1: (a)Typical I-V curve memristor. (b)Typical I-V curve of multiple conductance states of single device.

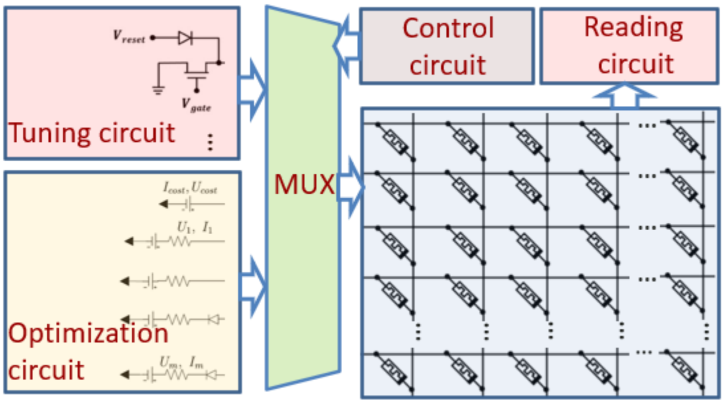

Figure 2. The circuit architecture of the memristor based analog optimization solver

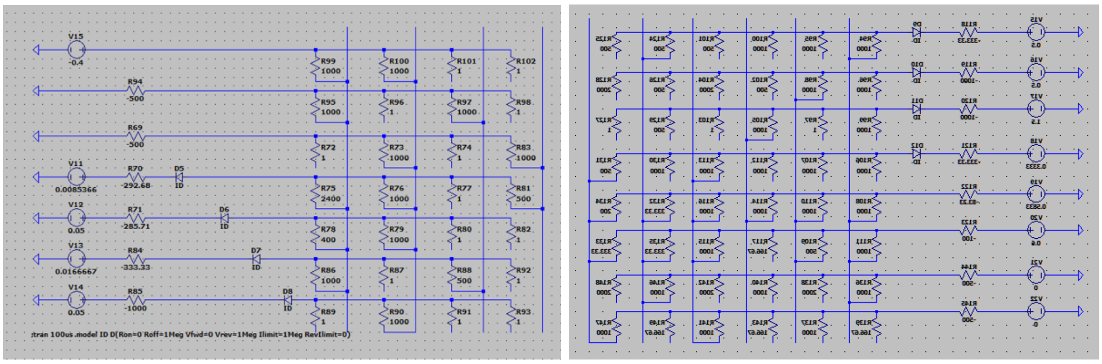

Figure 3. the circuit simulation solving a linear programming problem (left) and quadratic programming problem (right) using SPICE software.

Problem Type	Linear Programming	Quadratic Programming
Circuit Simulation	V = [5.0000 5.0002 0.0000 -2.0833]	V = [1.5001 0.50002 -0.500864 -1.00016]
MATLAB Simulation	X = [5 5 0 -2.0833]	X = [1.5 0.5 -0.5 -1]

Table 1. Simulation shows that both linear programming optimization circuit and quadratic programming optimization circuit have same results with MATLAB simulations.

Reference

1. Vichik, S., & Borrelli, F. (2014). Solving linear and quadratic programs with an analog circuit. Computers & Chemical Engineering, 70, 160-171.