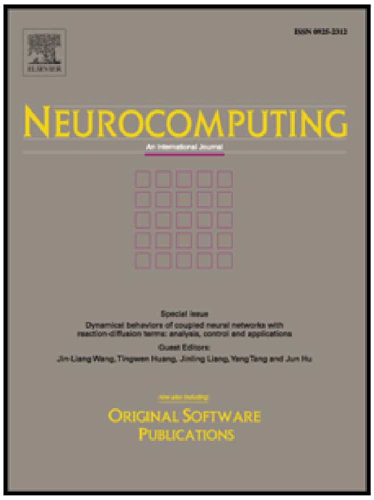

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Analog Circuits for Solving a Class of Variational Inequality Problems☆

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Abstract

In this paper, we present the analog circuits to solve a class of variational inequality problems (VIPs) based on the projection neural network (PNN) and inertial projection neural network (IPNN) algorithms. The proposed circuits are normative and only require basic circuit elements. The optimal solutions of VIPs are equivalent to the stable output voltages of the associated circuits. This paper also shows how to design analog circuits with projection operators (box constrains set and sphere constrains set) on the basis of PNN and IPNN algorithms. As a result, a class of variational inequality problems can be solved by proposed circuit frameworks. The effectiveness and superiority (with less computing time) of the proposed analog circuits are expound by simulating on three examples.

Keywords: Variational inequality problems (VIPs), projection operator, analog circuits.

1. Introduction

Variational inequality Problems (VIPs) are regarded as nature frameworks for equilibrium problems in science, engineering and economy [1]. A series of application about VIPs can be found in [2]-[15]. Many algorithms have been proposed to solve VIPs by a digital computer. However, for low dimensional problems, the computation time on digital computer may be overmuch.

One feasible way to overcome above drawbacks is to develop a analog circuit method. Many analog circuits had been designed up to now. In [16], a analog circuit for solving linear and quadratic problems was first proposed by Dennis, and further extended by Stern [17], Kennedy & Chua [18]-[20], Tank & Hopfield [21]. In Dennis's works, the primal and dual optimization variables were represented by the circuit currents and voltages, respectively. A typical version of Dennis's circuit was composed of resistors, current sources, voltage sources and diodes. However, in their work, the hardware implementation was limited due to difficulties in realization of the multi-port DC-DC transformers. A more practical circuit was presented for a multi-port DC-DC transformer which consists of amplifiers in Chua's work. In later work, Chua and Hopfield showed circuits to solve following nonlinear optimization problems:

$$\begin{aligned} \min_{x} \quad & f(x) \\ \text{s.t.} \quad & g_j(x) \leq 0 \ , j = 1, \ldots, m \end{aligned} \tag{1}$$

where $x \in \mathbb{R}^n$ is the vector of optimization variables, $f(x)$ and $g_j(x)$ are objective function and constraint function, respectively. The circuits proposed by Chua and Hopfield [21], the primal variables were represented as a capacitor voltages and dual variables were expressed as currents. In [19], Chua showed a feasible way to solve nonlinear programming problems with circuits and also proved their circuits could obtain the equilibrium points which satisfied Karush-Kuhn-Tucker (KKT) conditions. Wang proposed an electronic neural network to solve simultaneous linear equation problems in real-time [22]. In [23], a analog circuit with Differential Voltage Current Conveyor (DVCC) based unipolar comparators was presented to solve linear programming problems. In [24], Adegbege *et al.* presented an electric analog circuit to solve range of constrained control problems. In [25], Vuchik *et al.* proposed a passive analog circuit for solving linear programming or quadratic

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