Two simple memristive maps with adaptive energy regulation and digital signal process verification

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Main contents

1. Two kinds of memristor-coupled neural circuits are built to define two memristive neurons with exact energy functions.
2. Energy function for two memristive map neurons are defined and explained.
3. Linear scale transformation is applied to obtain equivalent memristive maps from memristive oscillators.
4. Adaptive law is proposed to control memristive maps, and circuit verification is finished.

1. Memristor-coupled neural circuits

Case I

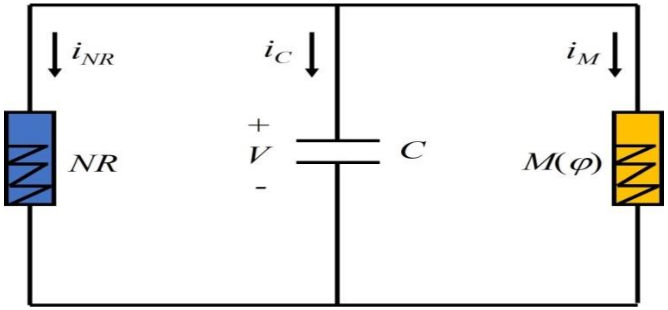


Fig.1 Case 1: A simplest magnetic flux-controlled memristor (MFCM) circuit.

Case II

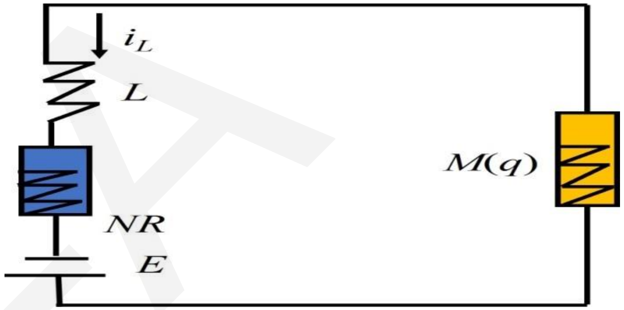


Fig.2 Case 2: A simplest charge-controlled memristor(CCM) circuit.

$$\begin{cases} C\dfrac{dV}{dt} = \dfrac{r}{\rho}\left(V - \dfrac{V^2}{V_0}\right) - \varphi V; \\ \dfrac{d\varphi}{dt} = \alpha\varphi + \beta V; \end{cases} \qquad \begin{cases} \dfrac{dx}{dt} = r(x - x^2) - cwx; \\ \dfrac{dw}{dt} = aw + \beta x; \end{cases}$$

场能量函数和哈密顿能量函数

$$\begin{cases} W_1 = \dfrac{1}{2}CV^2 + \dfrac{1}{2}L_M i_M^2 = \dfrac{1}{2}CV^2 + \dfrac{1}{2}\varphi i_M; \\ H_1 = \dfrac{W_1}{CV_0^2} = \dfrac{1}{2}x^2 + \dfrac{1}{2}cw^2 x; \end{cases}$$

$$\begin{cases} L\dfrac{di_L}{dt} = r\rho\left(i_L - \dfrac{\rho i_L^2}{V_0}\right) - (\alpha + 3\beta q^2)i_L - E; \\ \dfrac{dq}{dt} = aq + bi_L; \end{cases}$$

$$\begin{cases} \dfrac{dy}{dt} = r(y - y^2) - (\alpha' + \beta' u^2)y - d; \\ \dfrac{du}{dt} = a'u + by; \end{cases}$$

$$\begin{cases} W_2 = \dfrac{1}{2}Li_L^2 + \dfrac{1}{2}C_M V_M^2 = \dfrac{1}{2}Li_L^2 + \dfrac{1}{2}qV_M; \\ H_2 = \dfrac{W_2}{V_0^2(L/\rho^2)} = \dfrac{1}{2}y^2 + \dfrac{1}{2}(\alpha' + \beta' u^2)uy; \end{cases}$$

2. Two memristive map neurons

Case I

$$y_n = \frac{r\Delta\tau}{1+r\Delta\tau}x_n, z_n = \frac{r\Delta\tau}{1+r\Delta\tau}w_n,$$
$$\lambda = 1+r\Delta\tau, \delta = a\Delta\tau+1,$$
$$\gamma = c\Delta\tau, \mu = b\Delta\tau;$$

$$\begin{cases} y_{n+1} = \lambda(y_n - y_n^2) - \gamma y_n z_n; \\ z_{n+1} = \delta y_n + \mu z_n; \end{cases}$$

$$H_n = \frac{1}{2}y_n + \frac{1}{2}\gamma z_n^2 y_n;$$

Adaptive law for parameter growth

$$\mu_{n+1} = \mu_n + k\cdot\theta(p - H_n),$$
$$\theta(\cdot) = 1, p \geq 0, \theta(\cdot) = 0, p < 0;$$

Case II

$$\begin{cases} w_n = \frac{r\Delta\tau}{1+r\Delta\tau}y_n, v_n = \frac{r\Delta\tau}{1+r\Delta\tau}u_n, \chi = 1+r\Delta\tau, \xi = \alpha'\Delta\tau; \\ \varepsilon = \frac{\beta'(1+r\Delta\tau)^2}{r^2\Delta\tau}, \kappa = a\Delta\tau+1, \eta = b\Delta\tau, d' = d\Delta\tau; \end{cases}$$

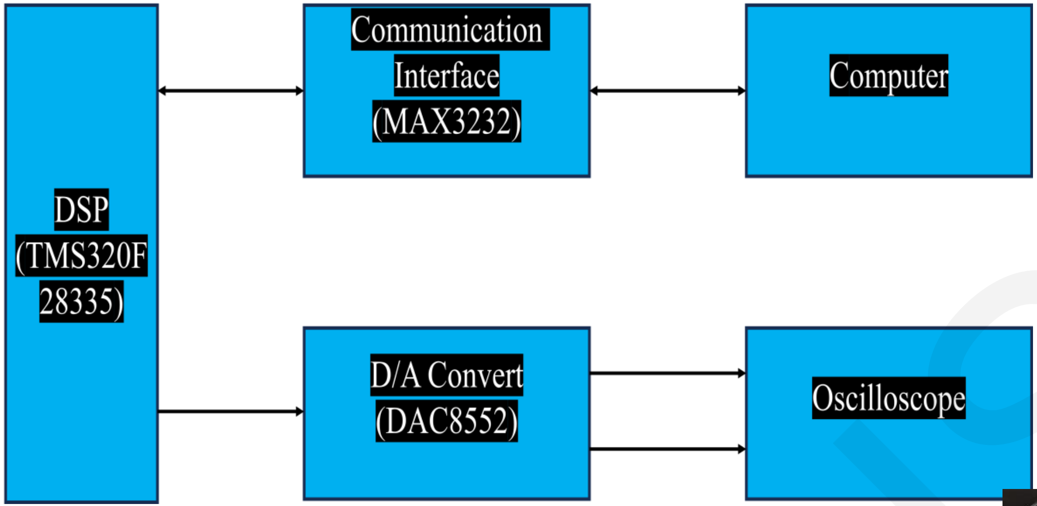
$$\begin{cases} w_{n+1} = \chi(w_n - w_n^2) - (\zeta + \varepsilon v_n^2)w_n - d'; \\ v_{n+1} = \kappa w_n + \eta v_n; \end{cases}$$

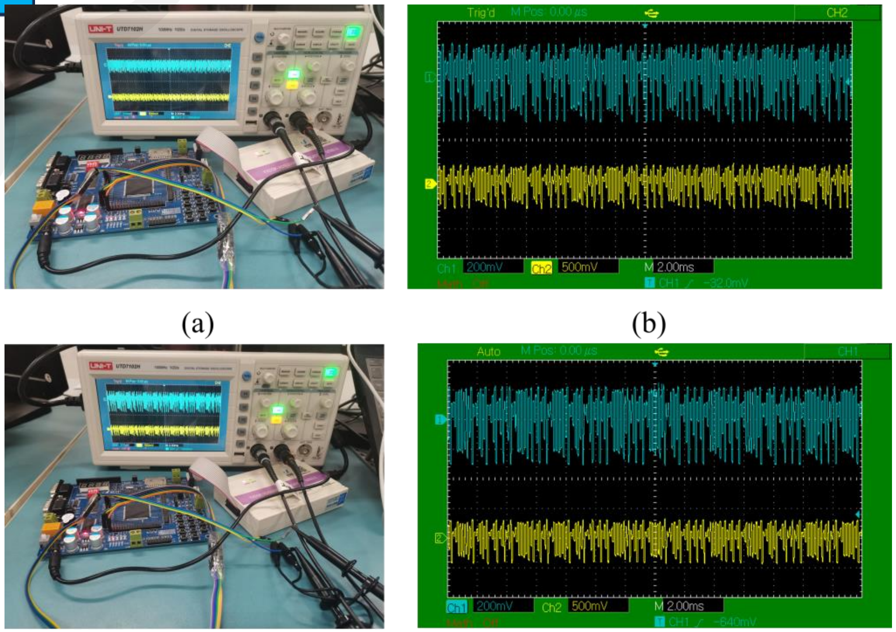
$$H_n' = \frac{1}{2}w_n + \frac{1}{2}(\xi + \varepsilon v_n^2)w_n v_n;$$

Adaptive parameter growth

$$\begin{cases} \eta_{n+1} = \eta_n + k\cdot\theta(p - H_n'); \\ \theta(\cdot) = 1, p \geq 0, \theta(\cdot) = 0, p < 0; \end{cases}$$

3. DSP verification





(a) (b)

(c) (d)

4. Scientific contribution and conclusion

1. Magnetic flux-controlled memristor can be used as inductive component, its connection to capacitor builds a reliable neural circuit.
2. Charge-controlled memristor can be used as capacitive component, its connection to inductor builds a reliable neural circuit.
3. Memristive oscillators can be converted equivalent memristive maps with exact definition of energy function by using linear scale transformation on variables.
4. An energy flow-controlled parameter growth law is suggested to explain the intrinsic adaptive property in map neurons.