Optoelectronic and Optical Device Characteristics for VCSEL-based Optoelectronic Neural Networks.

Andrew J. Waddie, Yves T. Randle and Mohammad R. Taghizadeh
Diffractive Optics Group,
Department of Physics,
School of Engineering and Physical Sciences,
Heriot-Watt University,
Edinburgh, Scotland, EH14 4AS.

Two-dimensional optoelectronic device arrays, especially compact, high-efficiency Vertical Cavity Surface Emitting Lasers (VCSELs)[1], have been increasing in array size while decreasing in overall power requirements. This increase in optoelectronic channel density has driven the development of optics-in-computing demonstrators to greater array sizes, such that some of these demonstrator systems have practically realistic computational processing power. In this paper we describe the design, construction and successful operation of a 64-neuron optoelectronic Hopfield-type neural network[2], based around an 8x8 VCSEL array and diffractive free-space optical interconnection. This network, shown in Figure 1, is designed to produce near-optimal solutions to a variety of optimisation problems associated with different types of telecommunications switch.

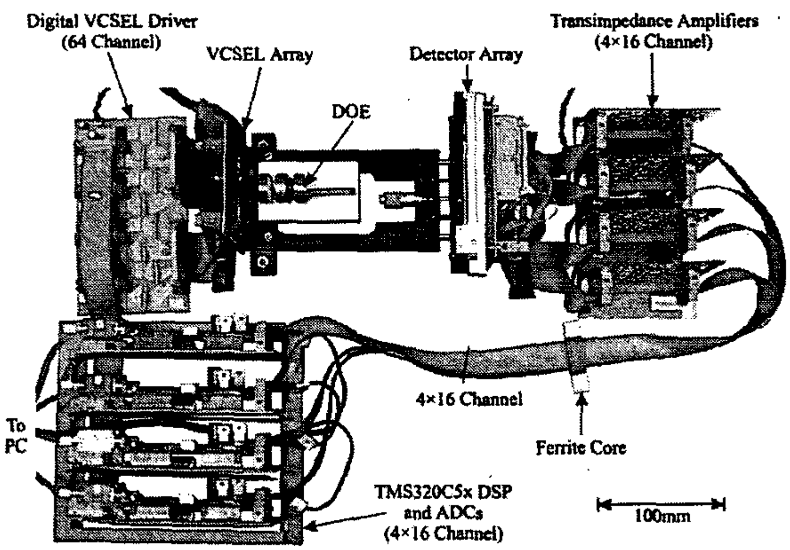

Figure 1: Optoelectronic Hopfield Neural Network

The Hopfield neural network is composed of a number of simple thresholding neurons that are connected to each other by fixed weight interconnection. Mathematically, the network is described by the following equations. Repeated application of these equations to the network evolves the networks to a state where only a subset of the neurons, determined by the precise weighted interconnection pattern used, will be left switched on. A,B,C and β are parameters which can be adjusted to ensure optimal performance of the optoelectronic network.

$$x_i(t) = x_i(t-1) + \Delta t(-I_i + C).$$

$$I_i = \sum_{j=0}^{N} W_{ji} O_j$$

$$O_i = \frac{1}{1 + e^{-\beta(AI_i + B)}}$$

In the optoelectronic demonstrator system, the sigmoid-like thresholding function is provided by a programmable electronic feedback system (provided by Texas Instruments digital signal processors)

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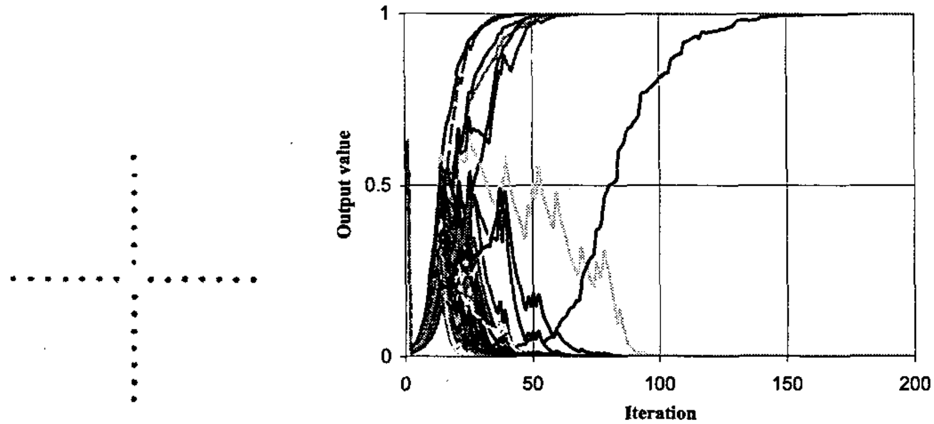
and the inter-neuronal weights (W_{ji}) are provided by a diffractive optical element (DOE)[3]. The electronic-optical conversion is provided by an 8x8 array of near-infrared (λ = 960 nm) oxide-confined VCSELs (manufactured by Avalon Photonics) and an off-the-shelf 8x8 Si photodiode array performs the optical-electronic conversion.

The completed optoelectronic system has been successfully operated using a number of different interconnection patterns. The first, shown in Figure 2(a), produces an output set which will optimise the throughput of a crossbar switch. In this case, each neuron is associated with a crosspoint in the switch and those crosspoints corresponding to "on" neurons are allowed to open after the Hopfield network has reached a stable state. Figure 2(b) shows a sample output from the system. Each iteration of the network is performed in 0.11ms and the network has fully evolved after ~150 iterations.



(a) Weighted Interconnection for Crossbar Optimisation.

(b) Dynamic Output from Optoelectronic Network.

Figure 2

Additional interconnection patterns, including Banyan, queen, knight and nearest-neighbour, have been operated successfully in the Hopfield network. These experimental data allow the optoelectronic hardware to be characterised fully and simulations of the network behaviour to variations in the optoelectronic and optical parameters are used to predict the robustness and scalability of the architecture. Initial analysis of these simulations would appear to predict a maximum Hopfield network size of 32x32 using currently available optoelectronic and optical technologies.

References

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