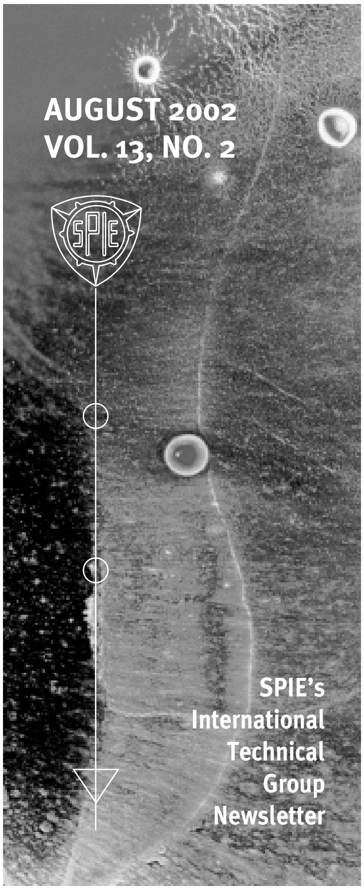

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Optically-interconnected computing at Heriot-Watt University

The Department of Physics at Heriot-Watt University, Edinburgh, has been working in the fields of optical computing and optical interconnects for the last twenty years. This article will look at two of the projects recently completed by the current Optically Interconnected Computing (OIC) Group.

The first of these is the AMOS (Analysis and Modelling of Optoelectronic Systems) project which is an investigation of the impact of a highly-interconnected, high-bandwidth interconnect on a commodity-PC-based cluster. We constructed a set of models to describe an optical highway consisting of a number of nodes interconnected by a free-space optical system.[1] Each node consisted of a PC and a smart-pixel array (SPA) providing the optoelectronic interface and, potentially, other functionality such as caching or low-level network operations (see Figure 1). The Institute of Informatics at The University of Leeds then used this description of the hardware in simulations of a number of algorithms. The models used for the AMOS project allow for a large degree of freedom in designing the optical system, choosing the PC architecture, and designing the algorithm to run on it.

It was clear that the relatively low bandwidth of the PC I/O bus would limit any system connected to it. It was found that the optical highway can enhance the performance of a PC cluster in two ways. First, the massive interconnectivity can be used to create large, completely-connected (or near-completely-connected) networks. This high connectivity reduces the latency of messages as fewer routing decisions are required and fewer network links are travelled. Second, some functionality—such as a random stealing load balancing algorithm—can be implemented on the SPA layer. Here, tasks are stored on the SPA

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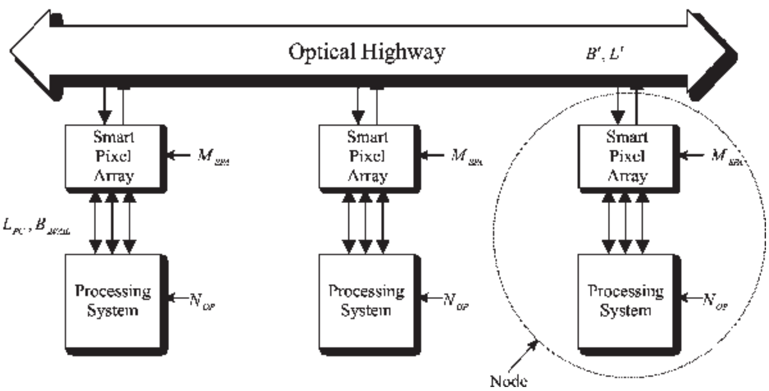

Figure 1. Schematic of the optical highway model used in the AMOS project. This shows the highest level of abstraction. Each parameter is obtained from lower level models of the system.

Optically-interconnected computing at Heriot-Watt University

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layer for their corresponding PC and transferred to them as required. If a SPA starts to run out of work, it randomly collects tasks from other SPAs. By implementing this at the optical-highway level, the large amount of network traffic created by this, often speculative, transfer of jobs is independent of the processing system's I/O bus.

In our group's second project, NOSC (Neural Optoelectronic Switch Controller), an optoelectronic neural network was constructed using optics to perform interconnection and off-the-shelf-electronics to provide neuron functionality. Although it is relatively simple to connect two people via a switch, real systems must accommodate many connections simultaneously: even under adverse conditions such as localized overloading or hardware failure. Neural networks have the ability to solve such scheduling problems efficiently, but limitations to the complexity and scalability of electrical interconnects on a conventional silicon chip have so far hindered the construction of any hardware.

In the system, arrays of detectors and VCSELs act as neuron inputs and outputs with complex neural interconnection patterns woven through free-space using a single diffractive optical element. Neural summation is simply the amount of light incident on a neuron's detector. All that electronics need do is choose the neuron's next response based on input light and communicate with the outside world. The first generation demonstrator,[2] constructed in collaboration with BT, took up the majority of an optical bench. The recently completed second generation demonstrator pushed integration and functionality further: the hardware now fits into a shoe-box. The third generation, currently at the concept stage, is intended to fully integrate the commodity components currently used onto a single chip. This level of integration is approaching that required for commercial viability.

The adaptation and optimization of algorithms for the specific hardware used, has considerably increased system scalability and performance. Indeed, doubling the size of the packet-switch routing problem only increases the time required to reach a solution by a couple of percent. Since the range of problems that a neural network can solve is vast, minimal alteration allows adaptation to a variety of tasks. These range from image recognition to general optimization and task allocation problems.

Heriot-Watt's OIC Group is now starting on two new projects. One, a European Union funded project, is to construct—with a number of collaborators—an optically-interconnected processor-memory bus for a multi-processor machine. The second is to integrate optical interconnects with reconfigurable silicon electronics in the form of Field Programmable Gate Arrays (FPGAs). Both of these will build on the successes of the previous projects.

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All-optical pulse generators for optical computing

Continued from page 3.

of first-pulse processing techniques from neural-network-modelling research shows that there are significant and meaningful computations that can be done with fully-parallel, pulse-based algorithms.

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Detection of 3D object position

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coordinate system of each elemental image to polar coordinates about the center of the elemental image. This increases discrimination ability.

Figure 2 shows an overall flow-chart of the proposed method. Each elemental image is transformed to polar coordinates and the *r*-coordinate is changed to ln(*r*) for the Mellin transform. The *f*-coordinate needs not be changed since the *f*-coordinate is not dependent on the size of the image. Each elemental image of the reference object is then correlated with the set of the elemental images of the signal object by JTC. The 3D position of the signal object relative to the reference object can be found by detecting the elemental image pair at angle zero that produces the highest correlation peak. The lateral shift represents the lateral spacing between two elemental lenses at angle zero, and the longitudinal shift can be found by the size difference of the perspective, calculated from the position of the correlation peak with respect to the center of the corresponding elemental image.

This approach can be improved further by non-uniformly placing the entire set of elemental images of the reference and signal objects in the input plane of the JTC simultaneously. This decreases processing time since correlations between all the pairs of elemental images are obtained at once.

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