

EMBEDDED DISTRIBUTION MODULAR CONTROL SYSTEMS WITH NETWORK INTERCONNECTIONS

V. I. Vinogradov, INR RAS, Moscow, Russia

Abstract

Modern Microelectronics opens new possibilities for Distributed System Developments in Experimental Physics, Engineering and other applications.

New Modular Microprocessor Systems with Network Interconnections for DAQ and Distributed Control applications are proposed and discussed. High-power general-purpose, specialized (communication and DSP) microprocessors work with distributed memory as Real-time Systems. Embedded Modular Systems for DSP and Control applications are developed in Industry standards (MicroPC with 2(4) slots of Industry Computer Systems (ICS) ISA crates (micro PC) or 4-8 slots of cPCI.) Real-time Multiprocessor Core and OS for Multiprocessor systems, which can be used effectively in Distributed Control, are discussed for different possible applications in Experimental research and Engineering-technological applications.

Compact Industrial Computer Systems (ICS) with active backplane and compact PCI-based systems (cPCI/PXI) with passive backplane are discussed as embedded RT-systems interconnected by Ethernet for Control applications. Distributed Systems with System Area Network (SAN) interconnections are discussed as advanced modular systems with parallel-pipeline Data processing for DAQ and Control Applications. Integration of Experimental Physics and Engineering systems are discussed on the base of the Joint model of DAQ, Trigger and Control subsystems.

1 EMBEDDED MODULAR RT-SYSTEMS WITH ACTIVE BACKPLANE

Microcomputers consisted of a lot of boards (plugged into a backplane) including CPU, memory, disk controllers, and serial/parallel ports. Some of the computers were based on the IBM PC (ISA bus) plug-in module, others were implemented as standalone (non-backplane) systems on a single board, and others were based on backplane buses (VME/VXI) as Single Board Computers (SBC).

Backplane-based microcomputers were used for data acquisition, process control, and different R&D projects, but were generally too bulky to be used as the intelligence embedded in devices. In the 80's, integrated circuits had advanced functions that

previously occupied entire boards which could be limited by single large scale integration chips, but later became a single-chip microcomputer or DSP. PC/104 and PC/104-Plus modules tend to be made from standard PC desktop and laptop components, supported by embedded Linux. PC/104-Plus adds the PCI bus, using a board-to-board bus (120-pin).

There was growing interest in IBM PC compatibility in embedded and non-desktop PC-based systems:

- PC chipset and peripherals compatibility could produce lower cost, simpler, and easier to support,
- PC compatibility gives advantage of the PC's OS (MS-DOS, Windows, Linux), language, and tools.

With new interfaces (USB, FireWire, Bluetooth), architectures (MIPS, PowerPC, ARM), and OS (RT-Linux, RTEMS), the embedded SBC platform was better for embedded modular RT-Systems.

- increasing embedded intelligence, many require user-friendly graphical & speech interfaces;
- growing need for any electronic devices to be interconnected (TCP/IP, PPP, HTTP, FTP);
- USB is replacing the serial, parallel, and PS/2 ports, Ethernet is everywhere and FireWire (IEEE-1394) is beginning to be used;
- Processors (numerous highly integrated ARM, MIPS, PowerPC, and x86 based application-oriented system-on-chip) are being developed;
- Linux is used in all computing, offering a low cost, open source solution with support for open standards, networking, communications, Internet and others.

Compact Modular Systems on the base of small Industry Computer System (ICS) MB with 2 slots are proposed as embedded Controller Stations (CS) and Working Virtual Stations (VS) interconnected by Ethernet 10/100 (TCP/IP) in Distributed networks. Each VS is based on Windows or/and Linux and each CS is based on RT-Linux, oriented to DAQ, Monitoring and Control. One of two PCI-slots is used for DSP-based DAQ and Control module. The second slot is used for extension or second Ethernet.

Field-buses usually have a modular approach in hardware and software to achieve different applications in economic ways. Most of today's computers have a traditional network (Ethernet 10/100, FireWire, USB) as standard connectivity. Field-bus concepts should include transparency to all of them. Serial buses (USB, FireWire) are used for medium and high-speed I/O

connectivity. SCI-interconnection supports scalable multiprocessor Clusters and high-performance modular RT-systems.

Another version of compact CS is developed with a 4-slot Micro-PC crate with a basic Communication processor module, which also includes dynamic and static memory chips and a set of standard interfaces (CAN-bus, RS 232 and others). RTOS should be used (RT-Linux, RTEMS) for DAQ and Control Applications.

2 EMBEDDED MODULAR RT-SYSTEMS WITH PASSIVE BACKPLANE

Single Euro-card (3U- format) is an international standard (IEEE 1101.1). The VMEbus allows 16-bit data transfers on the 3U-form factor (full data bus bandwidth is supported on 6U boards). Compared to VME(3U), cPCI(3U) is a more effective system for price/performance and there are difficulties in implementing PC functions in the VME architecture. 3U cPCI's bus performance is superior to 3U VME.

The cPCI/PXI bus supports full 32-bit or 64-bit data transfers in both single- and double-wide boards, compared to competing embedded PC board formats. cPCI/PXI also offers several advantages. The cPCI/PXI enables greater system flexibility extending the PCI slot limit from 4 to 8 cards. The cPCI was designed for industrial environments (like VME) and PXI was designed for Instrumentation Systems (like VXI). The 3U cPCI passive backplane is expandable and small. The backplane approach makes maintenance and upgrading of 3U cPCI modules much simpler. The cPCI/PXI (3U) boards support I/O required for Industry Automation, which requires distributed I/O.

cPCI supports the Fieldbuses for DAQ and Control, monitor, and report on processes. To address the needs of industrial applications, cPCI Systems support advanced networking functions on cPCI single-board computers (Ethernet 10/100, USB, FireWire and Field buses). Modularity provides access to the widest range of applications and gives flexibility of cPCI/PXI-based SBC support.

Embedded Modular CPCI/PXI (3U) System Hardware has advantages: 1) The small form factor (220-pin, 2mm connector) represents a good platform against shock and vibration for Control applications. 2) Complete PC modules (with graphics, Fast Ethernet, IEEE 1394, USB, Field-buses, flash memory, and 128 Mbytes of SDRAM) can be built on the compact flexible 3U-platforms. 3) Reducing power consumption is an important step toward low cost, and the move to smaller processing geometries has produced a reduction in power levels. Research shows that control devices

implemented with 3U cPCI typically consume less than ~20W. 4) In addition to an 8-slot cPCI backplane with 64-bit bus gives economic backplanes (passive and active) with using of equipment racks and enclosures with EMI shields. Modern embedded-computer solutions have a need for Windows-based software to achieve human-machine interfacing, networking and file management and deterministic hard real-time software for control applications (RT-Linux, RTEMS, QNX, OS-9, VxWork).

Linux support for PC-compatible embedded SBCs tends to be provided using the chips in a normal manner, including some specific functions like: Display controller modes, LCD panel control signals, PCMCIA, onboard solid-state disks, and Nonstandard functions (watchdog timer).

3 DISTRIBUTED SYSTEMS ON SAN INTERCONNECTIONS

Scalable Coherent Interconnections (SCI) developed as one of the best System Area Networks (SAN) for Advanced Multiprocessor Architectures, because of bus limits for a number of parallel processors in Distributed Data Processing systems. The first developer of SCI-based high-performance modular multiprocessor systems with hardware coherency was Sequent. Advanced Integrated RT-systems with Effective SAN Architecture on the base of standard Compact-PC modules (PC-board) and Link-modules (Dolphin's) for effective cost/performance systems according to a multilevel Physical Model are proposed for High-performance DAQ, Control and Distributed Data Processing in Experimental Physics Research. One of the best ways to construct cost/performance RT-systems is to use Industry Computer System MB (ICS MB), PC MB or cPCI/PXI, connected by SAN with different topology according to the application.

Distributed Parallel Data Processing Models include Symmetrical Multiprocessing (SMP), Massively-Parallel Processing (MMP), and Cluster Systems (RMC and NUMA). A RMC (Reflecting Memory Cluster) is a clustered system with a memory replication or memory transfer mechanism between nodes and traffic interconnect.

The highly modular structure of a Distributed Integrated System should support effective interaction between the distributed processor and memory with the help of Link- modules to the **System Area Network (SAN)**, which should include next structure levels:

- 1) **Nuclear level** consists of a set of Core processors, memory, I/O controllers and interconnections. New single-chip Microcomputers have short links, better access and data transfer time than out of chip memory on the same board.

- 2) **Atomic level** of a compact boards structure (A-Modules) of the System Model includes special-purpose or general-purpose processors. The simplest effective RT-system for DAQ and Control can be based on a standard PC MB with 1, 2 (Dual) or 3 (Quad) microprocessors on the board. The number of processor modules on the same bus is limited. Symmetrical Multiprocessing (SMP) is the basic Software Model for Multiprocessors.
- 3) **Molecular level** (Macrostructure) depends on system topology. A lot of Multiprocessor nodes can be interconnected by SAN ("Big Bus" Model) into large (Kilo-Processor) systems to support Distributed Integrated RT-Systems for DAQ, Control and Data Processing Applications.
- 4) **Interconnection** in Distributed Systems is based on Link-, Bridge- and Switch-Modules (L-Modules, B-Modules and S-Modules). The cost of communication speed decreases faster than the cost of pins and board space. Traditional communications are based on the bus, limiting the number of processors.

A practical solution is based on the use of packet-based signaling over many independent point-to-point links, which eliminated the bus bottleneck problem, but introduced a new problem - how to maintain cache-coherence in the shared-memory model of the system.

Weak interactions between processor modules are based on message passing (Ethernet). Intermediate interaction is based on external memory devices (disks, tapes) used in Clusters.

Strong interactions between Processor Cores are based on Direct Access into distributed memory and realized on SCI, which also supports weak interactions between processor modules. Strong SCI-interactions include small packet transactions (send and response split packets with echo). Packet Formats include writexx, readxx, movexx and locksxx commands, where xx represents the allowed data block length (number of data bytes, on the right after the packet header).

Scalability is problem of performance increasing in Multiprocessor RT-Systems (interconnected to Kilo-Processor systems).

Distributed-memory Model of SAN-architecture can support parallel-pipeline data processing (computing) in a single address space as an SMP-model. 64-bits address support 256 Tbytes in each node.

Cache coherency supports data availability for all processors in distributed parallel data processing Rt-system, which include many processors, attempting to modify a single datum or holding their own copies of it in their cache at the same time. Coherency, implemented by software or hardware, is a request to

prevent multiple processors from trying to modify the same data at the same time. Hardware coherency supports high performance (high price), but Software coherency provides good performance (low price).

Topology of modular RT-Systems should be based on a required set of selected Modules to develop a system optimal to the decided problem. It should be a matrix for DAQ with matrix detectors or 3D-topology - for 3-D images. In Control Fields the system should have a topology resembling the structure of large equipment (linear or ring).

Distributed SAN-based Systems should share a 64-bit SCI-address, where the high order 16 bits are used to rout packets to the appropriate node. System topology can be based on a simple ringlet, multi-ringlet, bridges or powerful switches for Parallel-pipeline strong interactions between processors. SCI is based on point-to point connections and supports transactions to all processor modules at the same time. The commercial Dolphin's L-modules provide an 800 Mbytes/s bi-directional SCI link for moving large volumes of Distributed data with small application-to-application latency (2.3 micro sec) and reduce the overhead of inter node control messages for the best scalability for multi-node applications.

The proposed Distributed network-based RT-system includes next nodes: Controller Stations (CS) connected to a Virtual Station (VS) collects RT-data and outputs Control data. A simple CS with an Ethernet port is based on a compact ICS MB with 2 PCI slots for a DAQ and Control module. The second port is used for extensions or for additional Ethernet. The VS should support simulation, monitoring and testing for professionals. Virtual Instrumentations and standard Application Software are based on a basic OS (Windows, Linux) and should work on the VS connected to a number of distributed CS with RT-Linux with the help of Ethernet10/100. Each VS should have access to the Multi-server level.

The proposed Joint General Model of Scalable Modular RT-System integrates DAQ, Trigger and Control Systems based on network (Ethernet) and SAN (SCI) interconnections. Compact ICS MB (A-Modules) with 2 PCI-slots and Ethernet should be a good platform for Engineering systems in Control technology area. Embedded CPCI/PXI-based nodes with SAN (SCI) interconnections should be a good platform for high-performance DAQ and Trigger Systems in Experimental Physics Area.