clusterFORTH Networking on an OPTO-22 LC2

FORTH Inc's clusterFORTH™ network protocol and a low-cost single board computer are successfully applied to a medium-scale distributed control application

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A Building Engineer reviews his computer's report of the energy used to heat and cool his building during the last 24 hours. The report shows an unusual increase in energy use in zone seven. Bringing up another report on the screen of his IBM Corp. PC-AT, the Engineer examines the last several hours of operation. For the last three hours, computer twenty three in that zone has been reporting temperatures twenty degrees colder than normal. Its gas burner has been on for those three hours, trying to increase the temperature. The Engineer suspects a failed temperature sensor, but wants confirmation before ordering a repair. Typing the command:

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23 BOX PLUG
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he's connected to the computer that controls the suspected heating/cooling unit. It will accept commands typed on his PC's keyboard, and display their results on its display. Concurrently, several channels of communication are flowing between his PC and each of 59 similar computers in the same building. That traffic, and his commands travel from his office to the roof-mounted heating/cooling units along a single 4-wire cable. To confirm his suspicion of the temperature sensor, he types a command to read its analog-to-digital converter:

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TEMPERATURE READ
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The result is displayed on the screen of his PC-AT—the sensor's reading is incorrect. The Engineer calls in the repair order.

The scenario illustrates the capabilities of an application recently developed by FORTH, Inc.. It performs Heating Ventilation and Air Conditioning (HVAC) control for a large multi-building complex. It's written in polyFORTH, our realtime operating system/language. Communications are handled with clusterFORTH network software.

clusterFORTH's beginnings

clusterFORTH was developed for the King Khaled International Airport automation project in Saudi Arabia. 400 computers sample 36,000 sensors, and control almost every aspect of the airport. Computer hardware is either custom-made or fairly expensive (large PDP-11's, for example).

An ordinary application

What's so unique about this HVAC application is that it's so ordinary. The hardware used to implement it is completely off-the-shelf, widely used, and relatively cheap. We used the IBM PC/AT, and OPTO-22's popular LC2 single-board computer. Analog and digital I/O is done with industry-standard OPTO-22 OPTOMUX modules.

The constraints on this application are also very common. Many widely-distributed data points must be read and written. The system must be tolerant of hardware failures—there should be no single point of failure. And while hardware should be independent for fault-tolerance, centralized control is necessary for data collection and the convenience of control from a single point. Finally, low hardware and software cost is important.

The application

Controls building complex's temperature and pressure

The application must heat, cool, and pressurize a complex of three buildings. Each building is divided into zones. Zones are areas with related HVAC interests; a large enclosed assembly area, for example. Each zone contains several airhouse units. An airhouse has the basic hardware to heat and cool the air, and to control its pressure with blowers. A building has up to sixty airhouses.

Building computers control airhouses

One computer in each building controls the operation of the airhouses in that building. It can make temperature and pressure settings, and set the "mode" that the airhouse operates in. A mode determines the airhouse's strategy for maintaining temperature and pressure. The state of the airhouses is periodically collected in a "snapshot" database for later analysis.

Some airhouses can report exceptional conditions, such as smoke alarms, to the central site. A few airhouses collect data such as static pressure, or wet-bulb temperature, that the building computer distributes to other airhouses. There are about 2300 data points to read and write in the complex.

Complex computer analyzes data

A central computer for the entire complex analyzes the data collected at the building sites. It has ultimate control over the building sites, though control normally remains with the buildings.

Implementation with clusterFORTH

clusterFORTH is a communication network for control applications. It runs with the polyFORTH realtime operating system/language. It provides "bulletproof" point-to-point communication between computers. The single physical channel is divided into several independent logical channels, each carrying a different type of conversation.

Master/slave at the low level

clusterFORTH is organized at its lowest level in a master/slave arrangement. The master computer is the more powerful; it has disk drives, a fast CPU, a keyboard/display, while generally the slaves do not. One master is connected to one or more slaves. The master assumes most of the network overhead, leaving the slaves free to execute the application.

Peer-to-peer at the high level

The part of the cluster that the programmer uses takes the more useful view that the master and slave are peers. When designing the conversations that take place over the network, one party is identified as absolutely needing something (acting like a master) and the other as providing it (a slave). From the application's viewpoint, the slave computer may assume the role of master in some conversations, the slave in others. Regardless, the lowest level continues to operate in a strict master/slave manner.

Code is developed directly on the slaves

Program code is developed directly on the slave computers from the master computer's terminal. The programmer develops programs interactively on the actual hardware that will run it. This method is far superior to traditional cross-compilation methods. Programming and debugging are very rapid.

Slave computers can be minimal

Even very inexpensive slave computers can be used. The slaves use the master's disk drives, terminal, and keyboard as if the slave actually had those peripherals. On the OPTO-22 LC2, over 16K of ROM and 30K of RAM is left available for user programs. The computational overhead of the network is barely noticeable. CPU speed was never an issue in this application.

Airhouse computer

Each airhouse contains an LC2. The LC2 uses a Z-80 microprocessor. It contains a single 32-Kbyte PROM socket that holds polyFORTH and the application. 32K of battery-backed RAM can store more program code and data. A real-time clock is used to maintain system time. A watchdog resets the LC2 if a software error causes the application to fail. Communication is handled with two RS-422 ports. One is dedicated to control the OPTOMUX I/O modules. The other is used by the cluster. Both ports run up to 19200 baud. The cluster port can be modified to go at 38400 baud. A software-readable jumper can be used for mode control information.

The LC2 performs all of the local control of the airhouse. It maintains pressure and temperature with a standard close-loop PID algorithm. It accepts settings from the building computer for temperature, pressure, and deadband. It monitors and reports alarm conditions to the building computer, such as smoke alarms. When the link to the building computer is down, the LC2 can maintain temperature on its own.

Since polyFORTH is multitasking, it can maintain a task for software debugging and development. That task can be plugged-into by a programmer using the building computer. As illustrated in the introductory scenario, debugging and development can be concurrent with the application's normal operation.

Building computers

The building computers are IBM PC/AT's with hard and floppy disks, color and monochrome displays. Hard disk is used for data storage, floppy for backup. The color display shows a diagram of the building with a dynamic display of any alarms. The monochrome display is used for programming, and displaying reports.

The building computers control the LC2's temperature, pressure, and mode settings, based on their knowledge of shifts, holidays, time of day, special pressure requirements, etc.

Data from the LC2's with unique sensors is read and broadcast to the other LC2's. Snapshots of the LC2's state are saved in a database for later analysis. The building computers maintain a database of the configuration of their LC2's (how they are equipped, etc.). Reports from the configuration and snapshot databases can be displayed and printed.

Complex computer analyzes building data

The complex computer is an IBM PC/AT with hard and floppy disk. It can access the building computers' disks for data analysis. An operator can perform any building computer operation from the complex computer by plugging into the building computer.

Network organization

Four clusterFORTH networks operate concurrently in the building complex over separate physical links.

Network 1 connects the complex computer as a master to building computer slaves. The building computers allow the complex computer to access their disks for data analysis. The complex computer can "plug into" the building computer, and thus perform any of their functions.

Networks 2-4 connect each building computer as a master to up to 60 airhouse computers as slaves. The building computers can plug into the airhouse computers. For development and database purposes, the airhouses can use their building computer's disk drives.

Results of the implementation

Access to many data points is efficient

Because the LC2's are so close to the data points that they sample, wiring is simplified. A reasonable number of points connect to each LC2, so the computational load on each LC2 is minimal. Relatively little data must travel between the LC2 and building computers, since low-level control is handled in the LC2. Data that travels a long way does so along inexpensive 4-conductor twisted pair wire, and under the protection of CRC error detection.

System is tolerant of hardware failures

Communication link or building computers failures are tolerated. LC2's are smart enough to maintain temperature without intervention of their building computer. Pressure can't be maintained, though because most airhouses lack pressure sensors.

An LC2 failure disables only one airhouse. Other airhouses in the same zone can often provide compensate for the downed airhouse. Watchdog circuitry in the OPTOMUXes leaves the hardware in a reasonable state if the LC2 goes down.

Transient communication failures have no effect. The cluster is tolerant of errors, retrying operations when necessary.

Low cost

Costs were quite low when compared to comparable solutions using special-purpose hardware. clusterFORTH's ability to extend polyFORTH's programming environment to the LC2's accelerated the software development.

Future directions for clusterFORTH

As a PLC replacement

A current project is replacing a Programmable Logic Controller with an LC2. Potential benefits are lower hardware cost, and much easier programming.

An LC2 clusterFORTH product

As an offshoot from this application, an LC2-based product is being developed. It will include at minimum, polyFORTH, the clusterFORTH network, and our driver for OPTOMUX I/O boards.

The LC2 is a very popular computer. It's widely available, very inexpensive, and well made. We haven't had a single LC2 failure in many hours or operation. It's maker, OPTO-22, has proven very easy to work with.

polyFORTH's rapid (re)programmability the means easy "tailoring" of the control application once installed. PID loops can be tinkered with—time constants, deadbands, etc. can be adjusted. The data base can be easily modified to accomodate changing specifications. The displays, reports, and user interface can be easily adjusted so they're *exactly* what the customer wants. The result is an optimum engineering solution, and a maximally happy customer.