Don't Get Run Over: The Evolution of PC Bus Technologies

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Over the last decade, there's been an increasing trend toward the use of PC-based automation solutions. In the early 1990s large automakers and other manufacturers began using standard PCs for machine control. These systems often replaced the compact, microprocessor-based solutions – programmable logic controls or PLCs – that were found in most plants at the time. Since then, PCs running Microsoft Windows and other operating systems have worked their way into a wide variety of industrial applications, experiencing growth that outstrips competing solutions.

As a result, the guts of a PC and the evolution of those components have become ever more important in automation. Traditionally, microprocessor advances have gotten the hype, with semiconductor companies touting faster and faster clock rates in their marketing. However, storage and I/O innovations are just as vital. The latter involves bus technology, which often forms the literal and figurative backbone of a PC. Thus PC bus technologies – past and future – are important to automation end users and the overall automation market.

As for why PCs have proven so popular in industrial settings, that has nothing to do with hype and everything to do with the bottom line. For one thing, the price of PCs, whether aimed at industrial or consumer use, has fallen and continues to fall steeply. In mid-2005, for example, the world's largest PC vendor offered a fairly capable machine for under $300. That was a 40 percent decline from the price of a similar system a year before and an even farther drop from the price of a similar system two years previous. Another bottom line plus is that a PC-based approach often leads to substantially reduced wiring expenses and significantly fewer components. Both factors cut costs and tend to make PC-based control very attractive when compared to the alternatives.

This good price performance ratio is coupled with an open architecture. That makes innovation both easier and not dependent on the whims of a single supplier. It also means that PCs in industrial settings can benefit from hardware and software advances in the commercial arena. Consequently, PC-based automation solutions have taken advantage of changes in bus architecture over the years.

Not Just a Blast from the Past: Older Bus Technologies

The first bus technology arrived with the original IBM PC in 1981. While IBM had its own name for the scheme, it was soon referred to as Industry Standard Architecture or ISA. It was at first an 8-bit system running with a 4.77 megahertz clock but that was extended by 1984 to a 16-bit version operating at 8.33 MHz. Typically, the bus allowed only one direct memory access channel for the movement of data into and out of add-on cards, such as those used to control industrial equipment. Power was supplied via 5 and 12 volt signals. Despite drawbacks having to do with speed as well as the installation and configuration of cards, ISA remained the dominant PC bus technology for years. It didn't totally disappear from consumer systems until the late 1990s. ISA is still around in automation systems.

An offshoot of ISA, the PC/104 standard defines both a form factor and a bus. The former was designed to meet the needs of embedded controllers. As a result, the PC/104 form factor has no backplane, with compliant boards and modules stacked atop one another. The form factor is also compact, measuring just 3.6 by 3.8 inches. Other features also make PC/104 suitable for industrial applications. For instance, the pin-and-socket connectors ensure rugged and reliable connections. The specification also calls for more ground pins to be mixed between signals and power. That improves the electrical integrity of any card and enhances its ability to perform under harsh conditions.

Electrically, PC/104 is no different than ISA, except for a lower bus drive current that cuts power consumption and minimizes component cost. Thus, it operates with the same timing, data rate, and other constraints. Originally finalized in the early 1990s, PC/104 has undergone a number of changes over the years.

Some of these tracked what's gone on in the commercial arena. There problems with ISA lead to the development of the Peripheral Component Interconnect, or PCI, standard. Released in 1992, PCI became the dominant bus by the middle of the decade. Unlike ISA, PCI supports plug and play. That means that the interrupts on cards are assigned to the device by firmware and not

physically configured via jumpers. For both consumers and automation system end users, being able to add a card without fiddling with interrupt requests and hardware is a significant plus.

The PCI bus is also faster than its predecessors, with original specification being a 33.3 MHz clock rate that allowed a peak transfer of 133 megabytes per second. Data was moved using either a 32 or 64 bit width and the specification called for both 3.3- and 5-volt signaling, an important fact given that semiconductors were moving from 5-volt to 3.3-volt and lower power supply specifications.

It also implemented bus mastering, a feature that enables controllers connected to the bus to communicate with other devices on the bus without going through the CPU. This approach significantly improved performance because it removed a potential chokepoint and allowed a data acquisition or DAQ card, for example, to interact with a disk controller directly. This could be done while the CPU itself was busy with other tasks that didn't involve the bus, such as fetching instructions from its local cache.

Later variations of the standard upped the speed, lowered the signaling voltage, and added a 16-bit bus. PCI was also incorporated into a version of the PC/104 specification, which is commonly referred to as PC/104+. The result is the equivalent of mixed ISA/PCI industrial system.

As happened with ISA, an industrial version of PCI emerged. Dubbed CompactPCI, this was based on the standard Eurocard 3U, 100 by 160 millimeter, and 6U, 160 by 233 millimeter, card sizes with a 64-bit PCI backplane. Cards meeting the CompactPCI standard can have all of the 32-bit and 64-bit PCI signals. They also must have a large number of ground pins to ensure adequate shielding and grounding, thereby minimizing ground bounce and maximizing reliable operation in electrically noisy environments.

The standard calls for eight slots in the basic configuration, double the number found in a desktop PC. Other industry-friendly elements include positive card retention, resistance to shock and vibration, and the use of standard, mass-produced PCI semiconductors.

Speed and Flexibility, Too: The Latest Busses

Despite the success of the various incarnations of the PCI bus, certain drawbacks forced the industry to develop newer technologies. One, the universal serial bus or USB, is intended to handle communications to peripherals such as printers, cameras, and other devices. It's proven very useful and popular for portable applications and today USB is found not only on PCs but also on PDAs and other handheld devices. The other relatively new technology was developed to address the problem that for certain applications, video graphic displays in particular, the PCI bus was just too slow. The solution is PCI Express, the successor to PCI.

PCI Express started appearing in desktop computers in 2004 and is fundamentally different from its predecessor. For one thing, the new bus has a point-to-point topology. This means that the entire bandwidth is available to every card, unlike the shared bandwidth of PCI. Data is sent serially in lanes, which carry 250 MBs per second in both directions. Multiple lanes can be grouped together in x2, x4, x8, x12, x16, and x32 widths, so that a bandwidth-hungry device can be hooked up to a large data pipe.

Using the initial signaling frequency provided by the specification, the x16 configuration provides four GBs per second, 30 times the usable bandwidth of a 32 bit, 33 MHz PCI system. With advances in silicon technology, chips will be able to handle faster signaling frequencies and the expectation is that eventually that will allow as much as a fourfold increase in the speed of PCI Express. The maximum value is expected to be reached when the clock bumps up against the practical limit for signaling in the copper wiring and traces of the bus itself.

Because of the differences between PCI and PCI-Express connectors, the same cards cannot run in both. Thus, systems will likely at first have a mixture of PCI and PCI-Express, with the initial uses of the faster bus probably being video applications. Machine vision, for example, is likely to be the first automation use of the new bus.

Eventually PCI-Express will become the standard. Predictions by market analysts are for a transition time of a few years and then PCI will disappear from consumer PCs. That switch will be helped along because there is software compatibility between the PCI and PCI Express. Thus,

there'll be no need for end users to buy new software and there'll be no need for developers to create and maintain two sets of code.

USB has been around since the 1990s and was originally intended to connect such relatively low speed peripherals as keyboards, mice and printers to a PC. With the advent of the USB 2.0 specification, the maximum data rate was increased to 60 MBs (480 megabits) per second. That made it fast enough to be of use for large scale data transfer and of greater interest for automation applications.

In many ways, USB is easier to use than a traditional, internal PC bus. Devices are hot-pluggable, which means they can be added or removed without having to shut down a computer. USB devices are automatically detected when plugged in, so that the operating system automatically installs and configures the device. Low power devices can draw current from the host PC, eliminating the need to run a separate power line. Up to 127 devices can run on a single port and by adding hubs, even more can be connected.

Data can be transferred either asynchronously or isochronously. In the latter case, transmission of a set amount of data is guaranteed to be complete in a given amount of time but it may not be error free. Since automation systems often have to respond to events, they can benefit from the ability to signal urgent messages asynchronously.

A final automation benefit of USB is that virtually every commercial PC today ships with USB ports. This universality means that USB can be used without paying extra for the capability and while reaping the cost savings of mass production.

Important Points for End Users and Suppliers

While there hasn't yet been an industrial version of PCI Express announced, there may be one some day – just as there was for ISA and PCI. That's because industrial and automation applications are different in some important ways from typical consumer and business PC uses. Some are physical, such as operating in dusty or humid environments where vibration is common. Others are more market oriented. Both impact PC-bus choices for automation applications and both point to features that should be in any vendor's product line.

An example of a market driven difference is the long lifetime of automation systems. An office PC is obsolete within a few years and so switching to a new bus can be done every five or so years, if need be. Any PCs that depend upon the old bus will be gone and the transition to the new technology is easier because of that.

The same isn't true in automation situations. There a bus long abandoned by consumer PCs will continue to be used. ISA, for instance, is still found in industrial applications. So automation systems must continue to support old buses. A case in point of how this is done can be found in Advantech's Industrial PC family of wallmount and rackmount chassis systems. These are available with a mixture of PCI and ISA slots in various configurations.

Another difference between consumer and industrial markets can be found in the need for revision control and support. Manufacturers of consumer PCs frequently change their motherboard configurations, swapping in such things a new video chips when they become available. Because automation systems can be directly involved in the operation of large industrial plants, changes that are undocumented to the end user can't be allowed. After all, the end user may want to buy exactly the same setup at some later time. So products should be manufactured with strict revision control. Again, the Industrial PC family provides an example of this, with engineering change notices fully documenting any revisions.

Automation applications also differ from consumer and office systems because they're often part of a larger system. So a PC-based solution by itself does little good. Instead there must be a complete package, with the platform, I/O, and software all present. That package must include needed support.

This can be done in a number of ways. Advantech, for instance, offers the Industrial PC computer system, the FPM line of industrial flat panel monitors and the AWS line of industrial workstations. The product line also includes the KW softlogic control software adhering to the IEC 61131-3 programming languages and the universal network controller, or UNO, fanless line of rugged, embedded PCs. Advantech also has also ISA and PCI bus DAQ cards and serial communication cards supporting the RS-232, RS-422, and RS-485 standards. These handle the interface between the PC and external instrumentation and controllers. In addition, Advantech

also provides a complete 3U/6U CompactPCI solution including chassis, CPU board, DAQ card, and serial communication card. Together with round-the-clock support, these products provide end users with a complete solution.

In addition to these market-derived differences, the physical requirements also impact automation solutions and bus choices. In some environments, a system's reliability can be boosted with the removal of all internal moving parts. Advantech's fanless UNO products are an example of such a more robust solution. In other automation circumstances, there's room for a display but not a keyboard. In that case, a touch screen may be the answer, with one case in point being Advantech's TPC family of touch panel computers. Finally, some situations call for a rack mounted PC with a wide array of choices. For such cases, Advantech offers a line that runs from an ultracompact 1U 2-slot chassis to a 7U chassis that sports 20 slots.

To further improve the match of specific solution to a given situation, Advantech offers a build-to-order service, which includes assembly and test of the product. That's complemented by a custom configuration service, which ensures that the final, delivered product is set up correctly according to customer's configuration requirements and is ready to go. In addition to build-to-order and custom configuration services, Advantech's Global Logistic Service provides global logistics and return material authorization (RMA) services. Systems can be shipped to wherever a customer desires and get RMA service locally.

Despite these differences between office computers and automation systems, one common need for both is that newer applications, if possible, should run on and benefit from the latest technology. This requirement includes the PC bus. Employing the latest technical advances allows for the use of the most recent innovations in software and silicon.

That may be difficult to accomplish with automation systems because such keeping up with such advances has to be coupled with a vendor's provision of and support for older boards. The implication is that not only must vendors have PC technology know how but they also must have automation knowledge. Single board computers from Advantech, for example, support Intel's 486 processors, which is obsolete as far as consumer technologies go but which is still quite useful in automation applications.

Conclusion

Advances in PC bus technology have caused bandwidth to climb from mega to gigabytes over the last two decades, with such features as plug-and-play configuration and hot plugability being added. The disappearance of jumpers and the capability to add and subtract peripherals on an ad hoc basis has made the PC more useful. At the same time, PC-based automation solutions have grown from being something occasionally done to a driving force in the market. The combination means that bus technology has become important to automation end users and suppliers.

The special conditions surrounding an automation application – the long lifetime, harsh environments, need for revision control and support of older technology – impose requirements on a proposed solution. Using a standard PC may not be a viable solution. They're often not rugged enough, change internal designs and components too often in an uncontrolled manner, and abandon older technologies long before the automation market does.

Just as the standard office product won't do, neither with the standard office vendor. The vendor needs to have both PC and automation expertise, as well as being able to supply a complete solution with support of older technologies for years to come.

Advantech, with its extensive catalog and experience, meets these criteria. That can be seen by various examples, such as the Industrial PC, Industrial Workstation, UNO and single board computer families. There are also softlogic solutions, touch screen computers, ISA and PCI DAQ cards, USB, CompactPCI, a variety of serial communication cards, and other products.

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