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White Paper

Get on the Bus: USB in Industrial Applications

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For industrial automation users, technology giveth and taketh away. On one hand advances in semiconductors and software result in smarter and more capable computers and machines, making the job of automating a process easier and more robust. On the other hand those same advances can spell trouble. Automation products have long lifetimes that are measured in decades and not years. So advances in technology – particularly PC technology – may mean that automation products and applications have to change, sometimes painfully.

The question for industrial users then becomes what change should be made? And what can be done to avoid a repeat of this problem in the future?

Consider the PC's internal bus, the electrical pathway used, in part, for communication with the outside world. At this time and for that case, Advantech believes the answer to both questions is the aptly named Universal Serial Bus or USB.

This bus change in industrial PCs is a result of changes in the larger market. Currently, PCI-Express is on its way to becoming a new backplane standard for PCs. So automation users are faced with the prospect of changing how their devices interface with industrial computers.

As an added twist, embedded processor boards are increasingly popular and frequently these boards come with no extendable bus, either PCI-Express based or one based on another standard. For example, a study by Venture Development Corp. of Natick, Mass. predicted the share of shipments of larger form factor embedded boards, those larger than 70 square inches, will decline by 9.7 percent from 2004 to 2008 while the overall market grows by nearly 12 percent in dollar volume shipments over the same time period. The growth will come from boards having only USB ports and no extendable bus.

Any solution to this bus predicament must enable communication that is high speed, deterministic, robust, and capable of covering the needed distance. The solution also must build upon a long lived standard that is universally available.

USB meets these requirements. Virtually all industrial computers ship with multiple USB ports and they're on many other industrial devices as well. USB has the necessary speed and millisecond determinism, more than enough for almost all industrial users. With some modifications, particularly in the areas of securing connections and bridging long distances, USB can meet all of the industrial application criteria.

The Changing PC Landscape

The consumer world long ago abandoned ISA, the Industry Standard Architecture bus created by IBM in the early 1980s, in favor of PCI, the Peripheral Component Interconnect bus developed by Intel and others in the mid-1990s. Consumer PCs are now in the process of moving to PCI-Express, the standard debuted by Intel and others around 2004.

How soon PCI will disappear from consumer PCs is unknown. ISA hung on for years after the introduction of PCI, with boards sporting a mix of ISA and PCI slots appearing during the transitional period. It's hard to pin down an exact date when ISA became extinct in the consumer space but reports indicate that ISA was around for as long as decade or so after PCI was introduced. It also should be noted that ISA is still available in industrial PCs and the embedded industrial PC specification, PC/104, still calls for an ISA bus, although in a different form factor.

For technical reasons the switchover from PCI to PCI-Express may be faster than that from ISA to PCI. For one thing, the replacement of PCI with PCI-Express is transparent to software, thus developers don't have to rewrite code to port an application from one to the other. That feature makes the change much more painless than the transition from ISA to PCI.

Another benefit is that PCI-Express offers some significant advantages in enhanced performance, particularly with regard to high speed applications like video cards, gigabit Ethernet, high speed image capture, and others. Whereas PCI enables data transfers at 133 megabytes per second, PCI-Express in its current form allows a maximum of eight gigabytes per second in each direction. For that reason, major manufacturers of high end graphics cards like AMD subsidiary ATI and its competitor NVIDIA are increasingly offering PCI-Express chipsets. Other applications, such as high frame rate video capture, are also taking advantage of the speed offered by the new bus.

On the other hand, there are many different types and a great number of PCI devices, with both type and number of devices much more numerous than were around when ISA reigned. Thus, this legacy may act as a drag and slow the switch from PCI to PCI-Express. The date when PCI will finally die in the consumer space probably won't be known for sure until it's already effectively happened.

While the switchover is taking place, there will be a period when both PCI and PCI-Express slots is found in the same motherboard. Industrial users need to take this transition into account because it may impact them.

This change isn't necessarily bad news. For one thing, the greater graphics performance enabled by PCI-Express could prove beneficial in industrial applications. Today such applications increasingly have a rich graphical user interface and being able to update a GUI at greater speeds and with less drain on the CPU could be useful. In addition, machine vision applications could benefit from the higher throughput, with the result that capturing more images per second would be possible. Finally, it's possible that a PCI-Express based solution could eventually be less expensive than one based on PCI, once manufacturing volume increases.

In general, industrial users need to take advantage of the latest technology and being able to put PCI-Express to work in particular could pay off in a number of areas. The problem becomes one of I/O, communication with peripherals of all kinds. Industrial users still have some ISA boards, although that number has been declining for years. There are presently many, many PCI boards in use, providing connections to a wide variety of devices.

What's more, such now obsolete internal busses, whether ISA or PCI, offer speed and determinism. All provide access to a PC-derived clock, an eight megahertz one for ISA and 33 MHz for PCI. They also both can deliver megabits of data per second. Thus these internal busses supply significant advantages in industrial applications, benefits any replacement also needs to provide.

Thinking outside the Box

The solution, Advantech believes, literally involves out-of-the-box thinking. It's long been standard practice in industrial applications to have an internal PC bus and an external fieldbus, with the fieldbus handling communications throughout the plant floor. The internal PC bus, for its part, provides the connection between the processor and the outside world. This division worked but it does mean the internal bus and its architecture play an important role in talking to the external world. As a result, changes to the bus can have consequences far outside the PC.

If instead all I/O is moved out of the PC chassis, such problems vanish and advantages appear. One consequence is that innovations and advances to the internal bus no longer disturb field networks. So the internal architecture of the industrial PC can easily move to PCI-Express, with all the performance and cost benefits. It's even possible to run the latest version of the standard,

thereby ensuring that graphics cards and other applications benefit from the best possible performance and fastest speed.

Clearly, such a move should be made to an established standard, one with a long lifetime ahead of it. Otherwise, shifting the I/O outside of the PC will only lead to problems later, as the I/O method becomes obsolete and is replaced. Given the length of time automation solutions exist once implemented, the projected life has to be at least a decade and preferably longer.

Other necessary parameters of any out-of-the-box remedy are also rooted in the nature of industrial applications. These include speed, determinism, distance, and robustness. For the first, transmission rates have to be sufficient to meet data and control needs. In some cases, only a few bits per second will suffice but in others data rates have to be substantially higher, megabits or more. As for the second, most industrial applications can operate well with a time resolution of a millisecond or more.

The distance requirements are in the tens of meters range for the most part, although there can be cases in larger plant floors where longer runs are needed. Plant floors are frequently full of vibration and dust, with high humidity and other harsh conditions a factor in some settings. Thus, any solution has to be capable of handling the environmental conditions.

Finally, any attempt to move I/O out of the PC can't be to some standard that isn't readily available. The interconnect has to be found not only on all PCs but also be present on most industrial machinery as well. Meeting this criteria will ensure that implementation of the solution doesn't present an undue cost burden or require extensive upfront specialized specifications.

The Contenders

When surveying the ways in which this out-of-the-box move can be accomplished, there are a number of possibilities. These include wired approaches, such as various forms of Ethernet, Firewire (IEEE-1394), and USB. There are also wireless protocols, such as Bluetooth, different implementations of 802.11, and the recently introduced wireless USB.

Of these the two most universal are Ethernet and USB. Both are found on nearly every computer and an ever growing percentage of industrial machines. Both are expected to last for a long time and hence should be available a decade or more from now. Both also benefit from decreasing cost solutions due to increasing use in consumer goods. Finally, both have issues for industrial applications, and in particular industrial I/O, that require some careful consideration before either is selected.

Ethernet isn't a single standard but is rather a host of communication protocols. Versions of it have been around for over 30 years and it is today the standard for connecting all local area networks. Even wireless connections eventually run through Ethernet to reach the wider world. Versions of it also offer plenty of speed, which is one reason why market surveys show 100 megabit and gigabit per second Ethernet each showing up in four out ten planned industrial data acquisition applications over the next year or so. Other industrial uses should have similar penetration rates.

What Ethernet doesn't offer, at least in a native or widely available form, is real-time performance. As implemented in most applications, Ethernet doesn't prevent data collisions between competing nodes and doesn't offer any Quality of Service (QoS) provisions. Thus in a deterministic setting, such as is the case on the plant floor where a machine must service an interrupt without delay when an internal clock ticks, Ethernet will fail. Given enough traffic, the micro-second level response times of the network will balloon out to milliseconds and that can render Ethernet unreliable for real-time industrial applications.

There are, to be sure, solutions to these problems. Real-time Ethernet protocols exist. The key word here is protocols, indicating multiple and non-compatible methods. Thus, until a single standard emerges there's a chance of picking the wrong version.

One of the most promising ways to ensure performance is to build upon the IEEE 1588 Standard Precision Time Protocol. This standard synchronizes clocks with sub-microsecond accuracy, and this precision allows distant devices to talk via Ethernet in turn without stepping on any other communication. On the other hand, this does mean that devices and network stack implementations have to be constructed with IEEE 1588 in mind.

However, industrial users have another choice, one that doesn't require waiting for a standard to be finalized. USB, particularly since the advent of the 2.0 implementation with 480 megabit per second data rates, offers the speed required and is found on virtually all motherboards and in many industrial devices. That universality is evident in surveys of USB penetration among industrial users of data acquisition modules. USB penetration will jump from 25 percent a few years ago to nearly 50 percent in 2007.

It's easy to see way. In addition to being on every device, USB is also deterministic, offering millisecond response times. Those reaction times are more than enough for most industrial applications. There are versions of USB for portable devices like PDAs and another for wireless connections.

USB does have two shortcomings when being considered for the plant floor and both are physical in nature. The first drawback is the limited run, which is only five meters for a standard USB cable. However, that run can be stretched to 100 meters over CAT5 cabling and with the use of a distance extender. Such an extension allows USB to be deployed over the entire plant floor. For an example of the architecture using this solution, see the attached diagram. (Advantech USB DAQ solution architecture slide image here).

The second issue has to do with the USB connector. Made for hot swapping, the connectors allow for easy insertion and removal. There's no active latch such as is found in other types of connectors. Thus, it's possible to unplug a cable with a simple tug, which could be inadvertent but still bring down an entire plant floor network. Even without that problem, a vibration filled industrial setting could cause the connector to work its way loose, leading to an eventual communication failure.

Solutions exist for this problem as well. One is a screw lockable clamp developed by Advantech for both USB type A and type B connectors. (See picture) The screw clamps on the type A connector can be removed, allowing the cable to be used with a commercial PC. If present, the clamp attaches to a kit mounted on I/O and hub modules, enabling the cable to be held securely against accidental disconnect and ongoing vibration. This particular solution is low cost and is similar to the type of connection technology used for years to lock printer, serial, and other cables in place.

Recommendations and Conclusions

For industrial users, the advent of a PC bus architecture change presents both a challenge and an opportunity. The latter arises because the new architecture typically brings better performance and enables new applications. The former is due to the central role the bus currently plays in essential I/O.

By moving the I/O off of the bus and out of the PC, the problem can be averted and industrial users will then be able to take advantage of the improved performance of the new bus. However, the communication channel over which the I/O runs has to be carefully chosen, with such characteristics as universality, data rate, determinism, robustness, and distance being important in the selection.

While no bus today natively meets all of these criteria, simple and inexpensive modifications to USB will allow it to satisfy all of the needs of automation and industrial applications. These changes include the use of a distance extender and a lockable connection. With those enhancements, none of which involve developing new standards or changes to drivers of other software, USB can provide a pathway for data acquisition and transmission as well as for control signals in industrial settings.

Done properly, this solution will provide a case where the best part of the old saying will repeat. Technology will giveth – and then giveth some more.

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