State-of-the-Art Virtual Instruments

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The definition of virtual instruments and their history from the mid 1990s to today is reviewed. A glimps of the future of virtual instrumentation is presented as well.

Virtual instrumentation grew from a need for a "user-defined" rather than a "vendor-defined" system. Breaking a system down into its components, starting with the sensor, measurement device, computer with operating system and application software, allowed an architecture meeting this need. For a technology like virtual instrumentation to evolve, these components had to be based on the right hardware and software platform. The late 1970s and '80s saw the big computing giants, IBM and DEC, create mainframe computing systems using the first IEEE-488.1 instrument interfaces. These general-purpose interface bus (GPIB) controllers connected the first digital instruments from Hewlett Packard, CAMAC and Tektronix to form automated test and measurement systems. But they were not what you would call *mainstream*.

The 1990s were very important, with the IBM PC (or compatible) typically running MS-DOS moving from a completely "textual" environment to one of visualization with the release of Microsoft's Windows Operating System. It wasn't all PC compatibles running Microsoft DOS (Disk Operating System) in the marketplace. Apple Computer offered a true 32 bit bus architecture called the Macintosh NuBus (patented by Texas Instruments) running on an operating system called MacOS. It was clear these platforms were going to drive measurements and analysis with a graphical user interface (GUI). This was the beginning of virtual instrumentation. The advent of mainstream computing technologies allowed virtual instrumentation to evolve from the most simple of measurements to advanced graphical system designs.

Virtual instrumentation was one of many use cases justifying the rapid need for computers. These new economies of scale produced two very important needs for the industry to take off: lower prices and improved quality.

Interface busses have made a similar evolution that now allow for data streaming rates of up to 250 MB/s. Beginning with GPIB in the 1970s and '80s, traditional measurement devices could be connected to a computer for the first time, allowing programmable software to control the device. As PCI (peripheral component interconnect) came of age in the '90s, plug-and-play data acquisition boards began to gain popularity. Measurement hardware could now be placed inside the computer controlling it. The data rates also began to significantly increase to 110 MB/s. PCI has evolved in the past few years into PCI Express, which allows data streaming rates of up to 250 MB/s across four bus channels, enabling a total GB/s streaming rate. Modern virtual instruments are taking advantage of these developments to enable customized, flexible data collection at faster speeds than ever before (see Figure 1).

Semiconductor technology has most recently solved increases to processing power with multicore designs. Advanced communication bus protocols connect devices with systems.

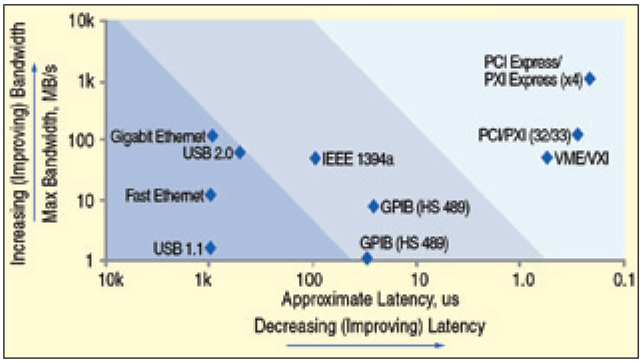

Figure 1. Various interface bus speeds and latency.

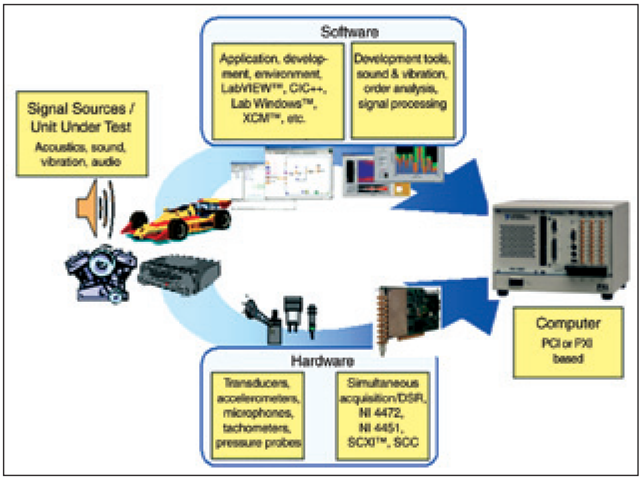

Figure 2. System elements of virtual instrument for condition monitoring.

Virtual Instrumentation

The first component of a virtual instrumentation system is the machine you intend to monitor. Second, transducers such as accelerometers, velocity sensors, proximity probes, tachometers, electrical power transducers, and thermocouples convert machine-generated signals such as sound, vibration, temperature, pressure, power consumption, and others into a measurable voltage. Third, cabling and perhaps signal-conditioning hardware connect your transducers to a measurement instrument (see Figure 2).

This is where traditional box instruments differ from virtual instruments. In a traditional instrument, this cable is connected to a box that contains data acquisition hardware as well as dedicated software for signal analysis and display. In a virtual instrument, the measurement instrument is a standard PC with installed data acquisition hardware and software that converts the PC into a measurement instrument. Finally, software (for measurement and automation) controls the acquisition hardware, provides a monitor-site man/machine interface (MMI), and interprets acquired signals for monitoring, and assists in diagnosis. Software can also provide functions such as signal interpretation, report generation, and data sharing. Overall, the application is broken into five functional areas: signal sources, signal conditioning, signal acquisition, measurement analysis, and presentation.

The advantage of moving out of the traditional box instrument to PC-based, virtual instruments is the flexibility, modularity, and possible customization you obtain. By having software-driven data acquisition on a PC, the software can be programmed however the user desires, rather than a preset list of possible functions. Additionally, by having the software running on the PC with plug-in data acquisition, the hardware can be swapped out when different measurements are desired or the system needs to be expanded.

Future Development

The future of virtual instrumentation is largely still driven by Moore's Law – the idea that every two years computer processor power doubles (see Figure 3). In the past, we have seen this as the impetus driving the creation of virtual instrumentation; now we are seeing it as spurring on the future. Embedded processors, first developed many years ago, are coming of age and now delivering the same power and processing capabilities as the personal computers of a few years ago. These faster, more powerful embedded processors have enabled a shift from PC based instrumentation to embedded virtual instrumentation.

Virtual instrumentation has been able to make the leap from PCs to such systems by integrating data acquisition into these powerful embedded devices. The small form factor and normally rugged components that comprise embedded computers have enabled

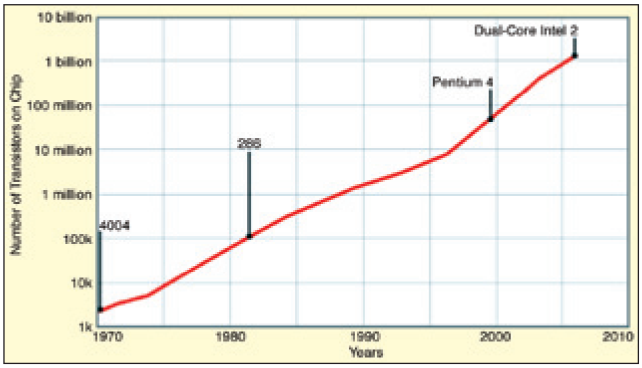

Figure 3. Moore's Law has continued to hold true, allowing for powerful PCs and enabling proliferation of embedded processors.

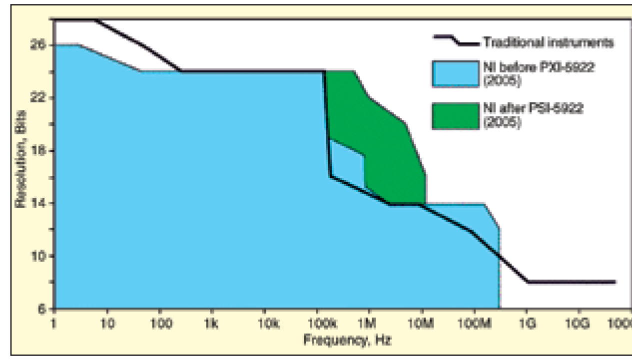

Figure 4. Recent developments in ADC technology have opened virtual instrumentation to much larger variety of data acquisition measurements.

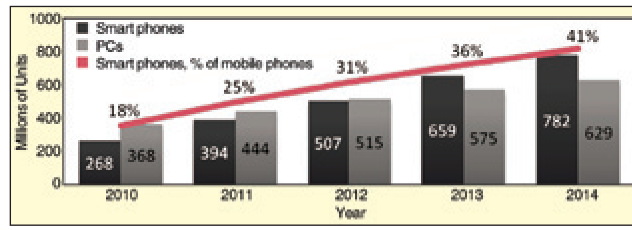

Figure 5. Number of smart phone subscribers has grown drastically, putting embedded data acquisition devices in millions of hands.

virtual instrumentation to move into a previously difficult sphere – embedded monitoring.

Though there are a number of situations that favor embedded monitoring with a small rugged device, remote monitoring of distant and hard-to-reach locations is one of the most common applications. By deploying a small data acquisition device with onboard intelligence, remote measurements can be made and analyzed without having to deploy a maintenance technician.

As an example of this move to remote monitoring with embedded devices, we can consider AMS Corporation. An aging nuclear reactor fleet has caused a drastic need for condition monitoring of critical assets in hard-to-reach or hazardous locations. AMS was able to develop a condition-monitoring system that could remotely make the needed measurements with real-time signal processing and decision making on board the device by leveraging embedded processors running custom software.

Coupled with the advances in computing hardware, we have also seen virtual instrumentation make large strides in data acquisition hardware. While in the past, virtual instruments were relegated to 16-bit multiplexed ADCs, today they can exploit 24-bit, simultaneously sampling ADCs (analog to digical converters) at rates of well beyond 200 kS/s. This hardware technology has opened techniques such as ultrasonic measurements that were otherwise not possible with slower sampling rates and less resolution. As indicated by Figure 4, we look toward increasing the sampling rates of delta-sigma ADCs beyond their traditional roles, breaking into the MHz ranges. In fact, there already exist flexible resolution Delta Sigma ADCs, such as those on the National Instruments PXI-5922, that sample at up to 500 kS/s at 24 bits and can go up to 15 MS/s at 16 bits.

The move of virtual instrumentation to monitoring devices is not the only benefit of the increased embedded processing we have seen over the past few years. The surge of mobile devices and specifically smart phones, shown in Figure 5, means that virtually anyone has an advanced computer in their pocket at all times. This has created a market for portable vibration data loggers that live on a cellphone. In fact, one such "app" already exists, which not only logs time waveforms for export but also performs Fourier transforms of the data. Though this software is in no way customizable, so it cannot be considered virtual instrumentation; software could and should be written that allows user-defined data acquisition on such a device.

There is another advantage of such a large smart phone subscriber base – hundreds of thousands of people can now access the internet from anywhere. Remember that one of the major features of embedded devices is that they can have network connections. If we were to create a web service on our embedded monitoring device, we could then access our machine's data on the go from anywhere in the world. This has immense implications in balance-of-plant monitoring applications. By equipping your maintenance staff with web accessible devices, either smart phones or tablets, they can now see data as they walk around the plant, pulling up particular machines on demand.

For all of this to be possible we need to have our embedded device publishing data to a web portal that can be accessed from a phone or tablet. But there is another crucial piece also needed here – a simple user interface. Traditionally, web services published data in a hard-to-read table format, because internet bandwidth restrictions limited the use of graphics. Today, with 3G and 4G networks, bandwidth-intensive graphs can now live in a web service without using all of the network's available bandwidth.

A number of tools have sprung up in recent years to fill this roll and build adequate user interfaces. Javascript, Flash, etc., have all addressed this need in much the same way that C and other text-based languages first addressed virtual instrumentation back in the '90s. And as there was with C, there now exists a knowledge hurdle to developing web user interfaces in Javascript or Flash. The creation of easily configurable drag-and-drop development environments, such as LabVIEW Web UI builder, enable people with little or no programming background to publish their data to mobile devices in an easy, intuitive way.

Conclusions

Over the past 30 years, virtual instrumentation has revolutionized how measurements are made, both in the lab and in the field. By leveraging virtual instrumentation, hardware can be endlessly configured and reconfigured for a large array of measurements with the click of a mouse. Virtual instrumentation has and will continue to evolve, taking advantage of the latest computing platforms and data acquisition hardware to continue to offer a modular, flexible architecture for condition monitoring measurements well into the future.

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