Advantages of using IEEE1394 for Industrial Condition Monitoring Systems (CMS)

History

For the past 3 decades advanced vibration analysis has be used in test labs all lover the industrialized world. The aerospace sector in particular has used such analysis in testing of jet turbines etc. The equipment would be tested under various conditions such as stress tests in a lab or even in test flights.
The sensors would be a combination of accelerometers, strain gauges, temperature sensors etc. Highly specialized digitizers (A to D converters) would be used to convert the signals to a digital (PCM) format for real-time or off line analysis by super computers. Advanced analysis methods have been developed for both time and frequency domain analysis.
As a result, it is possible to predict wear of gears, motors, bearings etc. The techniques are widely documented in scientific literature.
Unfortunately, until recently, these systems would not be feasible to deploy in the field and have been restricted to labs. Several factors such as cost and size have contributed to that fact.

The change

With the commoditization of the A to D converters (ADC) mainly driven by the computer and consumer electronics industry, it is now possible to find ADC's with performance exceeding 110dB (which is far beyond typical requirements for CMS) with very low distortion, and frequency ranges from near DC to 200KHz, for around one dollar. The generic PC is now orders of magnitude stronger than previous decades' super computers, and embedded Digital Signal Processors (DSP) have also seen significant reductions in dollar/MIPS.
This change has enabled the creation of entirely new applications called "Condition Monitoring Systems" (CMS). These systems are small and cost effective and can be deployed in production plants, wind turbines, news paper presses, oil and gas refineries etc. Some of the objectives of CMS's are:

- Predictable maintenance.
- Lower probability of emergency shutdown
- Safety and security, prevention of fatal leaks of chemicals etc.

In many industrial areas, such systems are required either by local regulations or by insurance companies. Often the costs saved in unscheduled maintenance calls, insurance fees and lost revenue from production breakdown far outweigh the cost of installing CMS.

Local CMS systems

In many cases, the monitoring of local devices is feasible. An example is an electrical motor with a local vibration and temperature sensor. The sensor inputs are processed by a DSP or micro on the device, and it can report deviations through a fairly simple asynchronous network to a console or data logger (generic industrial grade PC).

There is huge growth in such systems and they are especially feasible in remote facilities where energy harvesting and wireless technology can be used as well.
While these local CMS systems are valuable for some applications, other applications require more of a system level analysis.

Complex CMS systems
In a complex system like a newspaper printer or a packaging production line, the number of gears, motors, bearings etc. is very large. In such cases it is not feasible to perform local analysis for several reasons:

- Cost; each local device would require DSP etc.
- It is not always possible to isolate effects from one section to another.
- System level analysis will allow more precise pinpointing of the problem.

All systems, local or complex, will include a PC for data collection, storage and reporting (typically via Internet etc.). Today, the generic PC provides the most cost-effective processing and storage option.
So with that in mind it would be feasible for the CMS nodes to collect the data from the sensors and send it to the computer for storage immediately. This would reduce the amount of storage (RAM) required for the node and it would remove the need for any DSP on the node. The target is to minimize the cost and complexity of each collection point of which there are many and utilize the power of the computer (of which there is typically only one) to handle analysis and storage.

The problem
The optimal CMS system for complex systems has been described above. Unfortunately there are some problems which have to be overcome. In order to do system level analysis of sampled data it is vital that the data is sampled at all nodes at the same time using the same sample clock having approximately the same phase. If that is not the case correlation analysis will not yield predictable results.
The system will also require a network with guaranteed predictable bandwidth enabling the node to get rid of the sampled data on time, every time.
It is also important that the sampling clock is ‘jitter free’ to prevent aliasing errors in the sampled PCM data.

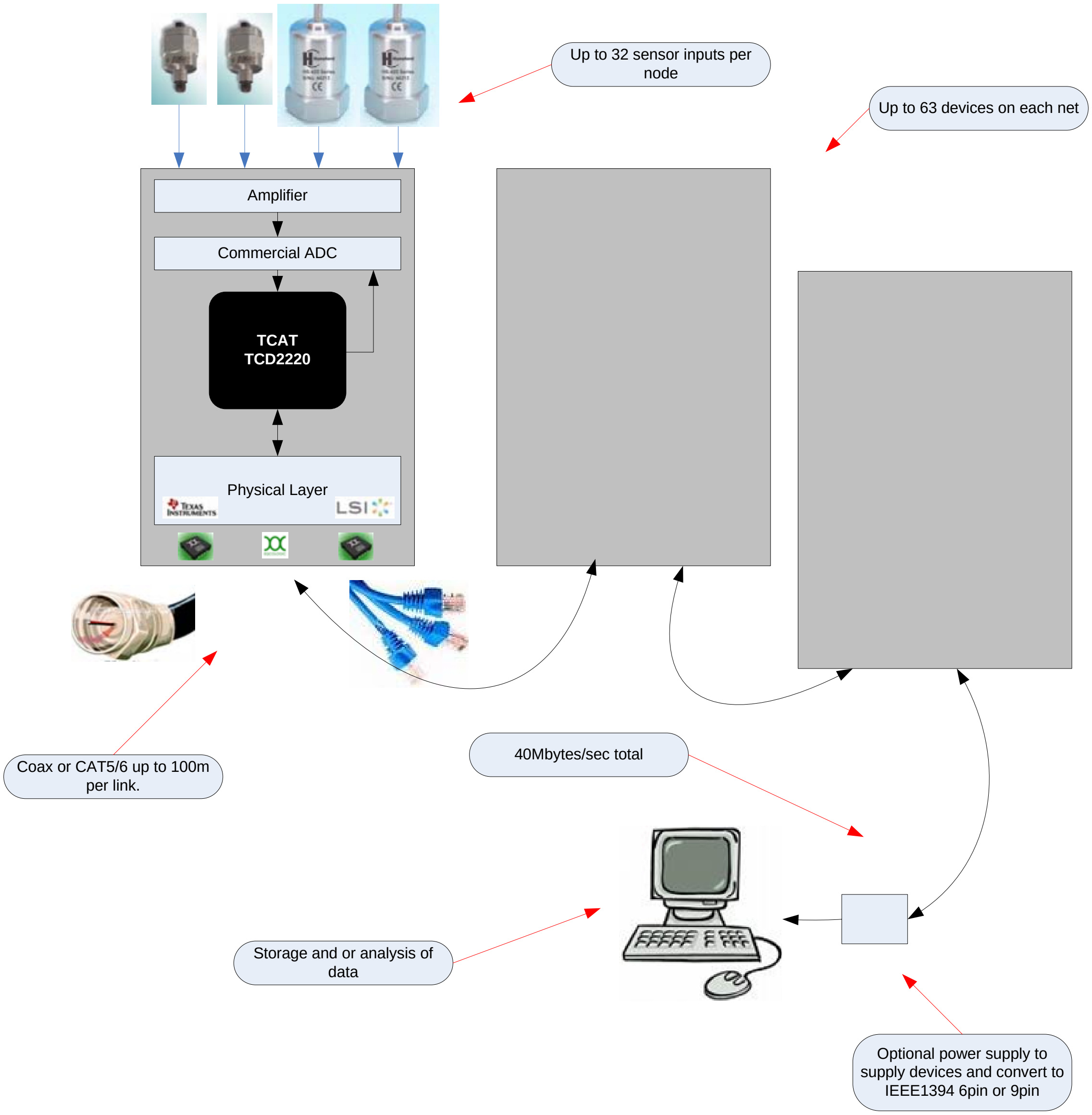
The solution
It is a well known fact that Ethernet has no Quality of Service (QoS) and it is not likely to have it anytime soon, in terms of qualified silicon etc. There is however another IEEE protocol which have all of this and has been on the market for more than 15 years. IEEE1394 (known as Firewire) is a full peer-to-peer network with QoS.
Unfortunately this protocol has not been regarded as a network due to the fairly short maximum cable lengths (4.5m), but lately the standard has been extended.
IEEE1394-2008 specifies a number of physical layer protocols and among those UTP (CAT5e/CAT6) and Coax. Those new physical layers specify distances up to 100m between each node and are getting a lot of interest in Industrial and Automotive applications.

The aforementioned solutions are already in use in military applications as well, such as the Joint Strike Fighter.
Today IEEE1394 is the protocol of choice for industrial camera applications. Some of these applications use the Coax solution, others use CAT5e. For shorter distances using the traditional STP cable a special industrial IEEE1394 connector and cable has been developed.
Furthermore a standard exist for transporting Linear PCM and other data over IEEE1394. This is covered under the IEC61883-6 protocol.
Some of the main advantages are listed below:

- Hardware level QoS supporting Isochronous service
- Network wide 'wall clock' with 40ns resolution for time stamping
- Time stamped linear PCM transport with synchronization to picoseconds precision
- Ultra low buffer requirements, typically 300us maximum.
- Any topology including daisy chain (every IEEE1394 node is a hub)
- Proven; more than 15 years on the market
- Multiple vendors and more than 1 billion ports have shipped to date.
- Multiple physical layers, cupper and optical.
- Used in Automotive, Industrial and Aerospace applications – approved for harsh conditions.
- Highly integrated SoC's available with little or no firmware development required.
- Based on international layered protocol standards (IEEE, IEC etc.)
- Support for power over network eliminates need for separate power supply.
- Bit Error Rate < 10^{-12}

An Example

The figure below shows a typical multimode CMS system with one central PC for data collection and analysis. Multiple devices on a daisy chain or any other topology (nodes can have more than two ports) provide data to a computer. All data are sampled using a synchronous low jitter (<30ps RMS) clock reconstructed from the inherent 'wall clock' (cycle master) or from a master device.
In case of synchronizing to a master device that device could obtain the synchronization from a GPS module which would then be used for all nodes in the network. In other words; there is no need for GPS modules in all the nodes.
Each node will time stamp the sampled data with the 'wall clock' allowing sample precise alignment of the data for storage and analysis.
If redundancy is required several computers could collect the same data without any extra overhead added to the system.
Each node would be capable of collecting 32 analog signals (in typical applications a node would collect 4-6 but scalability is an advantage). The sample rate of all nodes would be synchronous to a master node.
Utilizing 400Mbit/s the total number of channels in one network would be ~190 with a bandwidth of 48kHz per channel and a resolution of 24 bits.



The node would contain the traditional conditioning amplifier and ADC. We will not go into further details here as this is not specific to distributed CMS systems.
In this example the ADC connects directly to **the TC Applied Technologies TCD2220**. This SoC contains all the glue necessary to receive the PCM data from the ADC and the control ports (SPI, 2 wire, GPIO) to control and initialize the ADC.
The TCD2220 includes an embedded ARM7™ processor, IEC61883-6 streaming logic and an IEEE1394 Link Layer controller. The processor runs the IEEE1394 protocol stack and is available for user applications as well.
The physical layer is comprised of an IEEE1394b PHY (TI, LSI etc.). For short haul STP the only other requirement is connector and a passive network for ESD protection and balancing. For long haul coax the **EqCoLogic EQCO800SC** equalizer and mixer is used, For long haul UTP, CAT5e or CAT6 the **EQCO400T** is used.

For more information on the TCD2220, EQCO400T and EQCO800SC parts please refer to:
www.tctechnologies.tc and
www.eqcologic.com

