The Intelligent Sensor Platform

A new system for improving the design and operation of networked sensors

by

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Why improve the networked sensor systems available today?

1) Expensive, custom-built high speed networks for high data rates cost time as well as money to develop for specific applications. Yet, high rates of data processing are often necessary to properly detect or analyze the phenomenon of interest. If processing cannot be done at the sensor, then all data must be transmitted through the network until it reaches a server where it can be processed, requiring a high network bandwidth cost.

2) Useful data and unexpected trends are hard to find in large volume transmissions. This results in expensive storage of large amounts of data that at some point has to be processed by either humans or software, requiring more time and money.

3) Correlating data from various sensors can be difficult, especially if each has its own time reference. Sensors functioning in various locations have to generate their own time reference. If time references are not closely synchronized, attempts to correlate the event data can be difficult or impossible.

What is an Intelligent Sensor Platform or ISP?

The ISP is a flexible DAQ (electronic data acquisition) system specifically designed to be used for building intelligent sensor networks. ISPs are a DAQ system that can be easily customized for a wide range of applications where data filtering and timing is useful. The particular design of an ISP allows for improved data acquisition under many circumstances.

How can an Intelligent Sensor Platform improve data acquisition?

The ISP system is designed to reduce the amount of data to the pertinent, by moving the signal processing and analysis to the location of the sensor. By detecting interesting events and characterizing the signal, the cost of transmitting, further processing, and storage is reduced. An ISP can often replace an entire PC and DAQ card. An ISP can have a high rate of data processing at the sensor, but a low rate of sending data back across the network, allowing for the detection and characterization of transient signals.
How is an ISP different from common data acquisition systems?

Both types of DAQ systems take the electrical signals from a sensor and convert the voltage values into a stream of numbers. Most DAQ systems simply stream all the data to a local computer or network server for processing. The ISP can search for certain conditions, take samples of data around the conditions, and reduce the stream of data to a set of customized parameters. An ISP can also precisely time the event by a precision time reference. This is useful for any situation where time of an event needs to be known or data is going to be correlated with other sensors. The best application for an ISP occurs when interesting data is transient and needs to be processed at a very high rate for proper detection and analysis. An ISP is selective about the data it returns.

A well designed ISP is flexible and can serve many different applications. Many ISP's use a modular design to allow key components such as the analog signal processing, data converters, timing-references, and network connector to be swapped out. This allows for both cost reduction in terms of being able to add only the components necessary, and flexibility.

When is the ISP DAQ system the best choice?

1) The phenomenon or event is transient and well understood. The ISP excels at processing signals and extracting interesting data.

2) Multiple sensors in different locations must have data correlation for transient events. The ISP can detect, time tag, and report the events to a networked server where data is processed by other programs. A network of sufficient sensors would allow the detection and location of events of interest. Examples would be: lightning, seismic events, EMPs, sound event detection and location’s such as calls for help, gunshots, explosions, and auto collision, etc.

3) A complex system needs to be monitored for abnormal operation. Some sensor data has small periodic fluctuations in value, but simple threshold alarms would cause too many false alarms. The ISP can analyze the statistics of the sensor data and report problems only when a trend is present.

4) Some ISPs are capable of generating signals at precise times. Examples of use would be a network of beacons for receivers triangulate locations, or precise trigger times for seismic surveys signals.

What scenarios are better served by traditional DAQ systems?

1) Low cost DAQ systems, where slow periodic sampling less than ksps is needed and all data is saved. These are often called WSN (Wireless Sensor Networks) and are often used to measure slow changing phenomenon like temperature, humidity, or battery voltage.

2) A PC or PXI system is needed for directly processing the data at very high speeds (>200 Msp) and AC power is easily available. Examples would include situations like electronic warfare and advanced radar/radio systems were high speed broadband signals need to be analyzed.
3) The desired event detection and processing algorithm for the phenomenon are not well known. If the signal characteristics to be measured are still being experimentally determined or are beyond what the signal processing capabilities of the ISP are. To keep the power consumption and thermal cooling requirements of the ISP low, the amount of signal processing capability has an upper limit.

4) All sensor data needs to be stored for later analysis and the existing network data rate is already sufficient to handle the sensor's output. An ISP can also often stream data at the full network rate as well, however its signal processing and time-stamp capabilities might be under utilized and a simpler lower cost solution might suffice. If in the future, when the signal is better understood, data reduction will be used, it is often simpler to design with the ISP from the start and then upload the new data extracting code later.

How does using the ISP benefit a company?

The ISP is a specialized DAQ system designed specifically for building intelligent sensor networks. When using an ISP a company's effort is focused on implementing the detection and processing algorithm to extract the data of interest from the signal. The other parts of the DAQ system are already in-place and ready to be coupled to the processing algorithm. Generally, ISPs offer the capability to change the detection and characterization algorithms. So if in the future the requirements change the ISP can be re-configured, often right through the existing network, to handle the new requirements.

ISPs are generally cost competitive with many higher end data acquisition systems, but are able to reduce the requirements of the infrastructure needed to transmit, process and store data. They can also reduce the amount of time the human operator needs to analyze the data. With their flexibility, they can often fit a wide range of needs without having to buy and integrate many different technologies needed to achieve the capabilities needed for an intelligent sensor system. This reduces the amount of effort to maintain the system and to develop software for processing the data.

The ISP is specifically designed to be located at the sensor and preform the necessary task of reducing the data and communicating to the network. This means the ISP is designed for lower power consumption and more compact form factor then standard industrial DAQ systems. This reduces the cost of housing the ISP and building the power system for the sensor. Standard AC power doesn't have to be routed to the sensor. Solar or power of Ethernet can power the ISP. This combined with wireless networking allows for easy remote deployment without having to build any infrastructure to the sensor site.
How do you use an ISP for your design?

The basic ISP consists of four parts:

1) application specific electrical sensor or transducer with tailored analog front-end.
2) built-in digital conversion and timing functions.
3) flexible processing core with application specific code for event detection and feature extraction.
4) built-in web interface and network communication functions for reporting data and monitoring the sensor.

The application determines the interesting signal event detection criteria and then how to process the data stream around that event to extract the features of interest for evaluation. If the extracted features meet certain requirements then the features are sent to a server over the network. There are three methods for building the processing core: use the basic built-in functions, have the ISP vendor build a custom core for you, or use a software development kit to build your own.

Once the processing core is programmed into the ISP and the sensors connected, the ISP is ready to be deployed on the network. Using a web-browser or configuration utility program the sensors can be configured, activated, and monitored. On some ISPs, it's even possible to upload new processing core code over the network, allowing the ISP to adapt to new requirements.

The ISP allows the customer to focus on the processing core instead of building and integrating the entire DAQ system. Without the ISP the intelligent sensor system either has to be a full custom designed system or an effort to collect and integrate the various pieces needed to give the system the necessary functionality. Both methods involve a longer development cycle, require a larger team or collection of engineering skills, and have uncertainty in both the final results and time required to build and test the new system. In addition to the system being ready for the algorithm to drop in, the ISP vendors will generally keep up with the latest technologies and how to best integrate them into the system. Not having to learn the details of and experiment with the latest technologies can save a company considerable time and effort.
What are the details of how the ISP works?

The detailed components and signal flow of the Intelligent Sensor Platform (ISP) is shown in Figure 2 below. The diagram is followed by a detailed description of each component and its purpose.

**Function of each block:**

- **Sensor**: A transducer or other electronic component that converts the phenomenon of interest into an analog electrical signal.

- **Analog Signal Processing**: filters, shifts, and scales the signal into the optimal range for the data converter.

- **FPGA**: A flexible programmable logic device that can perform many functions at the same time.
  - **Pre-detection Signal processing**: The digital values are scaled, amplified, converted, filtered to make signal detection work better.
  - **Trigger Detection**: The signal is evaluated against predetermined criteria. If the signal meets those criteria then the triggered condition is set and a time-tag generated.
  - **Time Tagging**: When a trigger is met a precision time-stamp is generated of when the trigger occurred.
  - **Post-detection Signal Processing**: The signal is processed before being sent to the storage buffers for further analysis by the microcontroller. This is typically compression, filtering, or statistics generation.
  - **Data Buffering**: This is usually a small high-speed buffer where data is held until it can be sent to a larger memory or transferred to the microcontroller.
  - **External Memory Interface**: Transfers data to a larger, but often slower external RAM for storage.

*Figure 2: Intelligent Sensor Platform detailed block diagram.*
• **External RAM Buffer:** Large off-chip RAM based buffer used for storing large samples of data. Modern memory can often transfer data in the rates of 100's of Megabytes/s to Gigabytes/s and store from 10's Megabytes to Gigabytes of data. The advantage of having the external memory connected directly to the FPGA is that the throughput is much higher and allows for capture of data at a much higher rate than traditional systems that use the microcontroller's memory via a slower speed bus linking the FPGA to the microcontroller. If the microcontroller is embedded in the FPGA, then they can share the same memory controller eliminating the need to transfer data between them.

• **GPS Timing Reference:** A GPS or other precision reference is used to create an accurate PPS (pulse per second) to use as a reference for timing signal data. If a GPS is used, UTC date and time, position, and GPS status, can also be obtained. If just a precision PPS reference is used, then UTC date and time must be obtained from a time server on the network. Most references will provide an accuracy of 30 ns RMS jitter from PPS-to-PPS and a UTC offset of less than 1 microsecond.

• **Microcontroller:** Used for higher level processing of the data and communication to the network. It can also run a network server used for configuration and systems monitoring.
  
  • **Higher Level Signal Processing:** Typically used for the last stage code to determine if the signal events are interesting enough to send onto the network. Code here is typically written in C using standard library and special DSP math instructions. Although, generally slower than the FPGA code at processing signals because of the lack of parallelism, the code is much easier to implement and change.

  • **Network Communications:** Data is sent to a network server from this module. Methods may include encryption and special communication protocols. This module also receives command, configuration, and monitoring code from the network.

The ISP also has some other components that are not shown in Figure 2, such as local data storage (flash RAM based), power filtering and regulation, status displays, and external GPIO (general purpose signal I/O) connectors. The GPIO signals can be used for such things as trigger-in, trigger-out, PPS out, clock out, etc. to synchronize multiple local sensors or communicate with other hardware systems.

**Conclusion:**

An Intelligent Sensor Platform can save time, money, and uncertainty in building a sensor network. The system comes with basic functions of conversion, timing, and communication built-in allowing the user the focus on developing the signal processing. ISP's are also optimized to be located at a sensor which allow for reducing the data locally at the sensor. Reducing the data at the sensor reduces the cost of having to transport, store, and process all of the signals data.