Combining the strength and benefits of wireless and fiber gratings Technology

By Peter Kung , QPS Photronics Inc

The problem

The biggest obstacle in the implementation of large scale sensor network stems from the cost and logistics of cable installation: Each electrical sensor must be connected by its own cable to a multiplexing hub, and many of these hubs are to be connected together into a server. In a typical structural health monitoring of very large assets such as bridges, tunnels and dams. Other more severe example of monitoring a flying helicopter and aircraft, where several hundred sensors might be required to study the strain and fatigue distribution in their structures during flight. The sheer weight of these cables would make such project impractical. Development of the wireless sensor network would provide the freedom from cables. Wireless sensor had borrowed the technology base of telecom wireless network: People imagine the benefits of millions of these wireless sensors sprinkled all over the place like STAR DUSTS, and these sensors will be smart enough to do the necessary signal and data processing. They will only communicate the summary data and condition of exception such as alarm and warning. The movement towards wireless sensors started in early 2000 and is gathering momentum. First driven by military and defense, they are spreading like wild fire. Wireless sensors have been the theme at Sensor Expo for the last four years. However, people realized that they still have a problem. Each of the wireless sensors is powered by a battery; unlike cell phones where users can recharge, these sensors need to be replaced when they are drained of the charges. If the wireless sensors run out of power, then they will stop working. The logistics of tracking the location of millions of sensors and to periodically replace the battery can be a big nightmare. In fact, the smarter you make these wireless sensors, the more power they consume and the shorter their useful life.

There is now a move towards shrinking the size of the wireless circuit in the hope that they will consume less power. There is also a new interest in the development of energy scavenging devices. We saw it as a new theme in this year Sensor Expo: remote energy supply for these remote wireless sensors. It sounds like we have solved one problem and created another.

The wireless sensor network

The example of a typical wireless network would be the SensiNet Services, provided by Sensicast; the following best illustrate their design concept:

SensiNet Services, the first totally integrated measurement system combining patented, state-of-the-art mesh networking sensor technology with the power of the Web to provide unrivaled flexibility.

Measure anything, from anywhere, without wires.

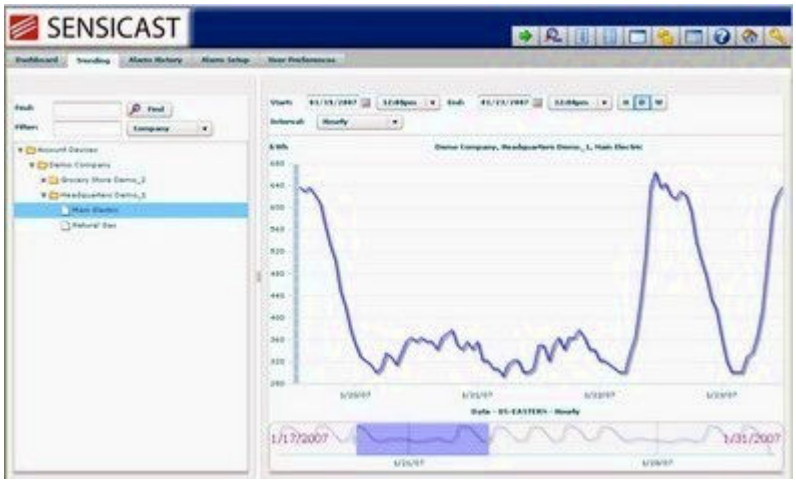


Fig.1 WEB based sensor network interrogation Courtesy from SensiCast

With SensiNet Services, any computer equipped with a browser is transformed into a high performance data logging system. All the power of traditional HMI and SCADA systems Software to Buy, Maintain and Upgrade . Fig.2 illustrates the implementation of such a wireless sensor network

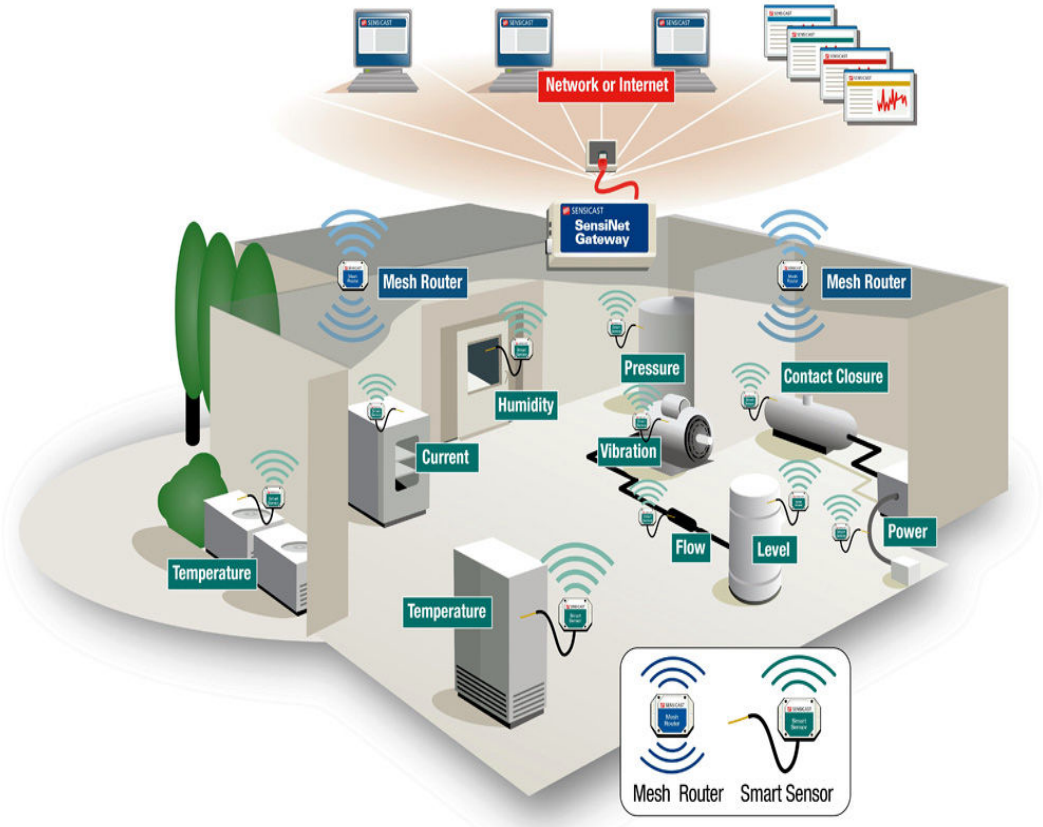


Fig. 2 SensiNet Wireless sensor network Courtesy of SensiCast

Introduction to Fiber gratings technology

Fiber grating is a new class of optical devices made by recording the interference pattern between two beams of UV light. The mechanism is as shown in figure 3. The interference pattern is formed by shining the laser beam through the phase mask which acts like a beam splitter: the optical fiber is placed within this interference pattern which is very close to the phase mask.

In addition, the optical fiber must be made photosensitive to record such interference pattern.

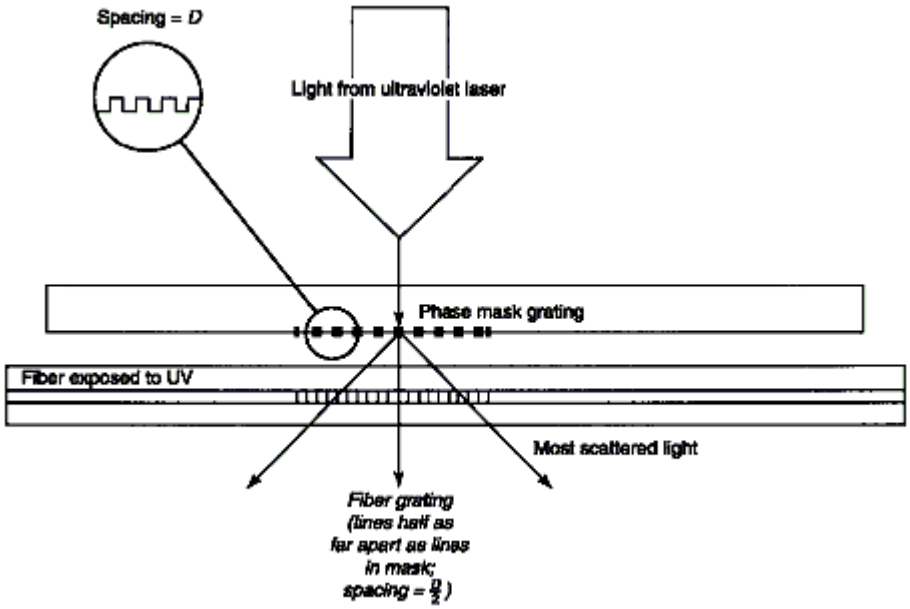


FIGURE 3 *Ultraviolet light writes grating in sensitive fiber core.*

Courtesy of Naval Research Laboratory

Each grating is actually a wavelength specific mirror and it is very useful for wavelength multiplexing and demultiplexing (WDM), where up to 96 color channels can be integrated into a single fiber cable. Fig 4 illustrates how these devices can be used as sensing element for both temperature and strain.

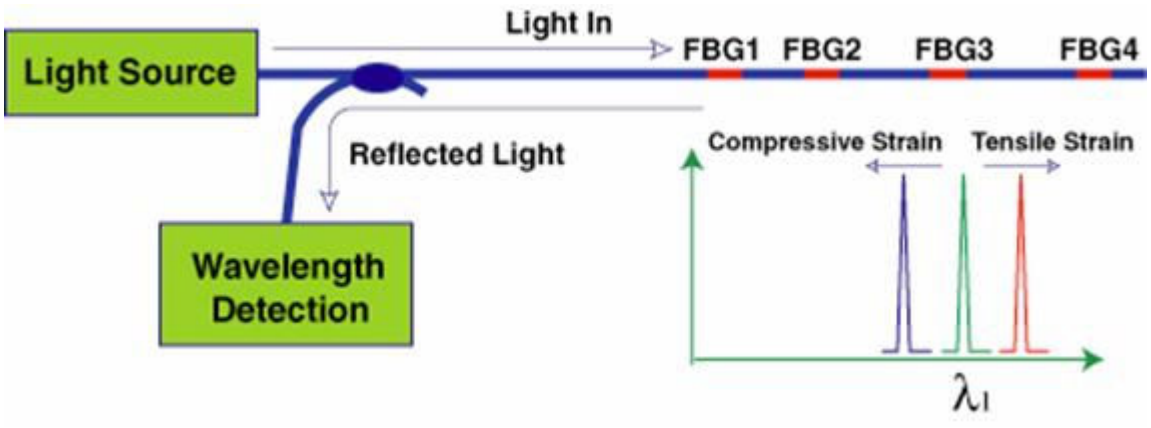


Fig 4 Fiber gratings used as strain and temperature sensors

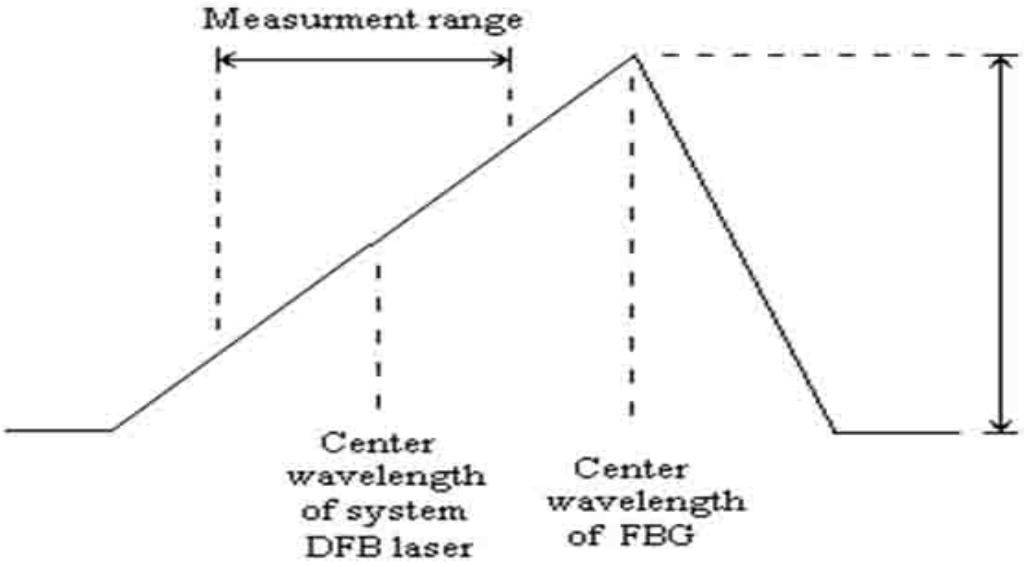
Courtesy of Hong Kong Polytechnical University

Fiber gratings vibration sensing, a new invention

Much of the fiber gratings products were designed for the telecom industry, these products are slowly being adapted for other sensor applications. One area is a vibration sensor for machine conditioning, especially in hostile environment, like power generators, transformers, machinery used in mining. The basic sensor structure is shown in Fig 5.

Fig. 5 Picture of the vibration sensor head , 15mm by 10mm Courtesy of QPS

Where the sensor head is a fiber grating with gentle slope, this slope is sensitive to temperature and strain and will move against a stationary interrogating laser, causing changes in light intensity. By placing another gratings with similar design within close distance, we can create a cavity. See Fig.6



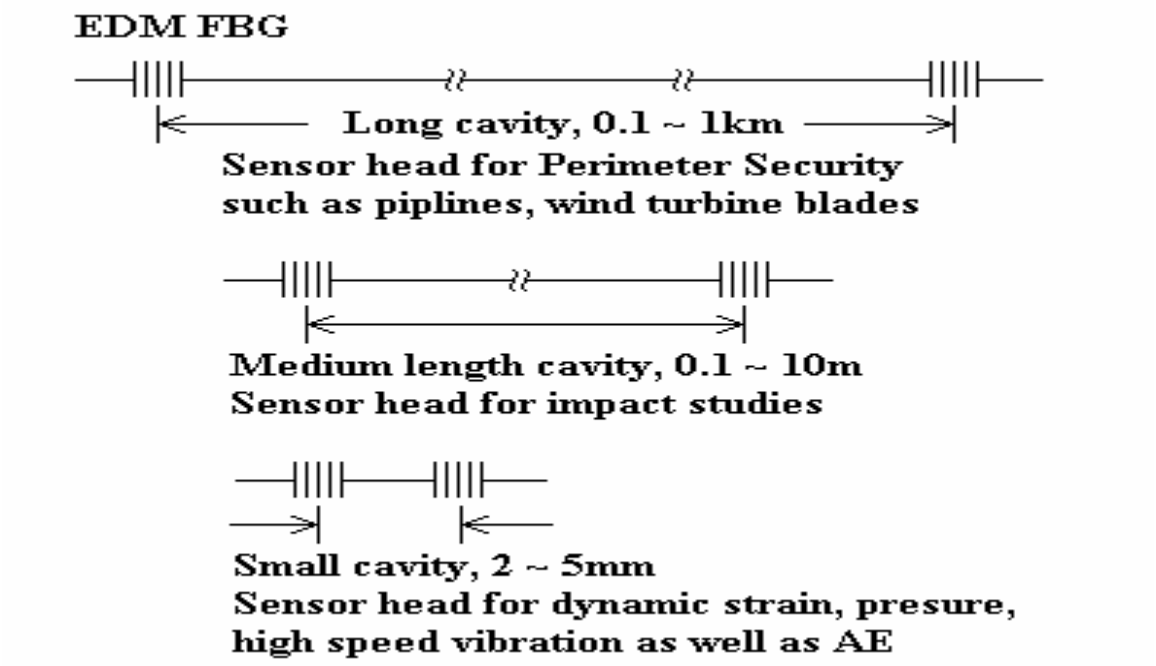


Fig.6 Design of the Edge Multiples sensor and the gratings cavity
Courtesy of QPS

Light from the laser becomes trapped between this gratings pair, forming an interference pattern, vibration causes changes in the optical path and the interference pattern follows the vibration signal. Short cavity structures are suitable for machine vibration measurement; longer cavity length devices would be good for impact, explosion studies and automotive crash tests. The longest cavity would be useful as hydrophones, seismic sensors and sensors for pipeline monitoring and border security applications.

The new invention has been patented by QPS Photronics Inc . The company has just released two sensor and system product families: A four channel HPS system with full vibration monitoring function and then an eight channels interface system which plugs into any data acquisition unit.

The hybrid solution

The fiber gratings sensors are passive, long life, immune to electromagnetic wave interference and works well in high temperature and pressure.
Each sensor is self-referenced because it works on its unique wavelength. Through WDM and TDM, a large number of these sensors can be connected to one interrogation hub. A fully loaded hub can handle up to 1600 sensors. You can identify the location of the sensor by its unique wavelength. Further more, wireless technology can interconnect all the fiber optics hubs; where each hub supports up to hundreds and thousands of fiber gratings sensors covering a large area, unlimited by the length of the cable (up to a distance of 25 Km.)

In other words, it might be a good idea to use wireless as a hub technology, rather than wireless sensors. We can use wireless to connect many hubs together in a mesh network. Via the web technology user can build a national or regional sensor network: yet being able to know changes happening at each sensor level. Fig 7 shows a hybrid solution with a star sensor network where there is only one sensor per channel.

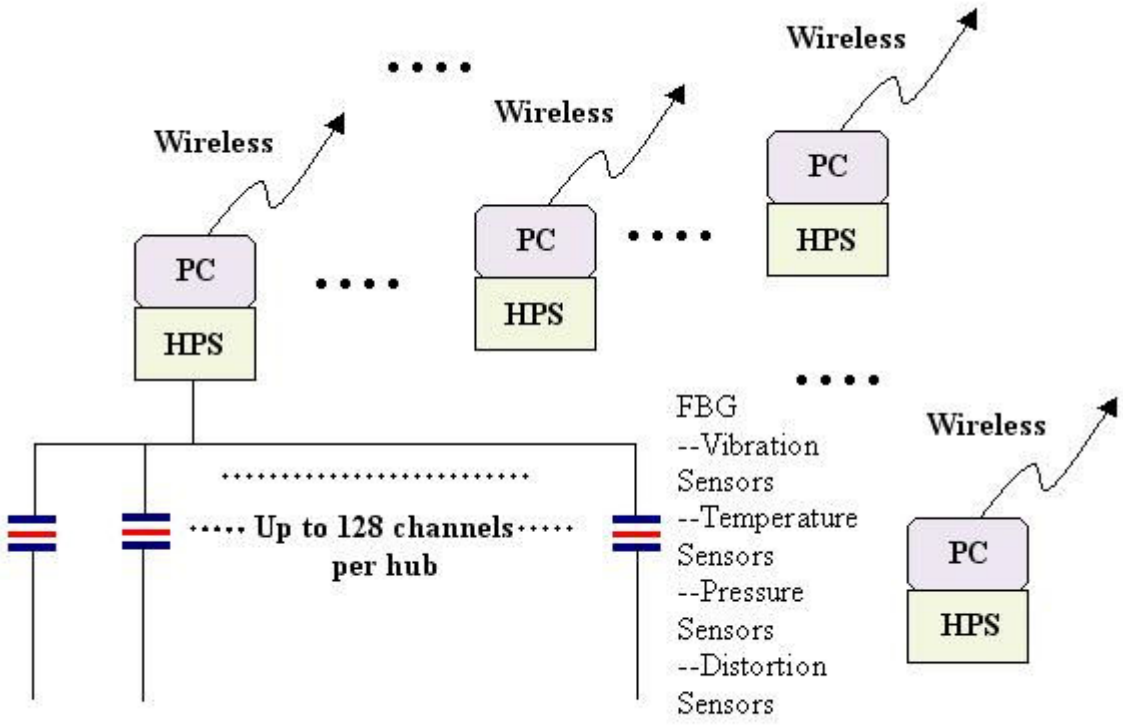


Fig 7 Phase 1 of the hybrid Solution
Sample Star Sensor Network interconnected by Wireless

Alternatively, fiber gratings interrogation units can be made into interface boxes with analog outputs which can be integrated seamlessly to existing data acquisition units; customers select the type of sensors they want, where it make sense they can use fiber gratings sensors, or they can place both types side by side to compare their performance. Fiber gratings might not be able to be converted into all kinds of different sensor function in a short time. This arrangement will give the customer total freedom of choice, use FBG sensors to cover large area sensor network where power is hard to come by or it is in an hostile environment. See Fig .8 Use wireless for smaller sensor networks covering well behaved environment and simple battery replacement.

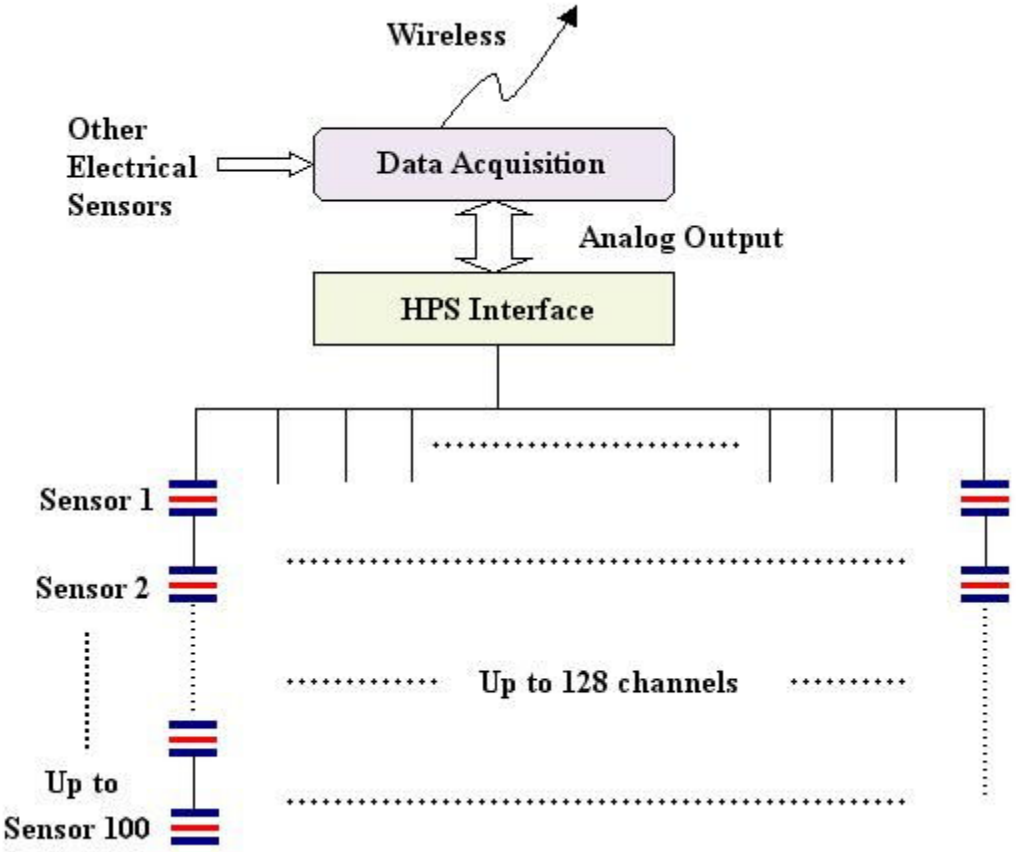


Fig 8 Phase 2 of the hybrid Solution
Massive Sensor Network, each hub is an interface box supports up to 100 sensors per channel.

The benefits

By tapping the strength of each technology, we can reduce the power issues of the wireless sensors; take advantage of their economy of scale and growing momentum, but apply these advantages on the hub. Each of the hub supports a star sensor network with several hundred fiber gratings sensors, each is expected to work for 25 years, without the need to do replacement of defective sensors, re calibration of the replaced sensor, or the replacement of wireless sensor batteries. With this proposed hierarchy, fiber gratings can be designed into many structural health monitoring applications; price will come down as the volume eventually builds up.
The benefits can be summarized below:

Lowest cost of ownership:

Eliminate replacements of defective sensors, their calibration and installation. Eliminate the cost and logistics of replacing several batteries to the wireless sensors during their useful life

Distributed Intelligence:

With the hybrid solution, signal conditioning and processing will be done at the hub level. Their electrical circuits will be shared by many sensors that belong to the same channel in the star network. It will be a more cost effective solution than having the intelligence built into each sensor.

Optimized use of bandwidth:

The sensor industry is a 40 billion dollars market in 2007, up to 250 million of this 40 billion is going to the wireless sensors. If every single sensor is converted to wireless, we might have billions of wireless sensors, these will exceed the growing number of cell phones. Cell phone and wireless sensors will start to compete for the same bandwidth. Adapting a hierarchy ensures a reasonable growth rate of bandwidth demand by the wireless sensor networks.

Manageable logistics:

Since fiber grating sensors can be connected by long fiber optics cables. The interrogation unit does not need to be placed in the same hostile environment together with the sensors; the interrogation unit can be placed where there is power, room temperature and where access is easy.

The hybrid solutions offer an intermediate solution; instead of eliminating all the cables, we can eliminate 95 to 99 % of the cables with their associated weight and logistics (each optical cable now carries 40 to 100 sensors.) In addition, fiber optical cables have a variety of sizes and weight: giving customers many choices based on their constraint. In fact sensor array can be directly embedded into composites structures and modules during their manufacturing. Essentially we turn these structures into SMART STRUCUTRES.

Need for more partnership and cooperation in the sensor industry

Each of the innovative technologies has its strength and weakness; there must be a matching of technology with the customers need. Unfortunately the sensor industry is still very much product oriented. In a product oriented company, one would try to get its products designed in everywhere --- even when it does not make sense! What customers want is a solution to a problem. It would be nice if companies in the sensor industry will extend their horizon into other sensor technologies and see how people can work together to give the end customer the best solution. It is not about a fight of territory, it is looking for the best match or the best combination. Semiconductor companies who tried to be all things to all people have already disappeared. Everybody now acquires a unique value added niche. Be it MEMs , Fiber optics, magnetic , ultrasound and Nano sensors , we all fit some where but not alone. Problems are getting more and more complicated. Why

don’t we work together as a team of experts, in full cooperation to do the best for our customers?

Peter Kung is the President of QPS Photronics Inc, a company specialized in fiber grating based vibration sensors and systems for machine vibration monitoring and other related field like pipeline and border security monitoring. He can be reached at:
peter@qpscom.com phone 514-697-4728 SKYPE : peter.kung.qps