Terrorist-proof buildings from new high-tech sensors

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Scientists develop a breed of sensors that can survive extremes of heat and pressure

Scientists have developed a new breed of sensors which can survive incredible levels of pressure and heat and that are helping researchers work out how to make buildings that could survive massive explosions. Professor Julian Jones, of Heriot-Watt University, will reveal the next generation of sensing devices at the Institute of Physics conference Physics 2005 in Warwick, heralding a new range of measurement and safety applications.

The three new types of sensor use specially-engineered optical fibres which respond to changes in their environment. They can monitor blast-waves from high explosives, structural safety in tunnels, bridges and buildings, bending in critical aircraft components, and deterioration in weapons stockpiles.

Most modern sensors are electronic and work on the principle that temperature, pressure or stress affects the electrical behaviour of the sensor. Usually, a computer measures these changes to produce a digital readout. But electronic sensors can be impractical, unreliable and even dangerous when used in the wrong conditions. They are unsafe in explosive environments and many medical applications, and are prone to interference when used in strong electromagnetic fields, such as in power plants, or magnetic resonance imaging. Fibre-optic alternatives, which work with light instead of electricity, have attracted serious interest and are beginning to monitor data which could never have been measured electronically.

The role of optical fibres in communications, as the basis of the telephone system and the internet, is well known. Much less familiar are the optical fibre sensors that have grown up at the same time. Measuring devices can be built out of a pair of these fibres, one to take the measurement, and the other to act as a reference. Light beams travel along the fibres, are reflected at the end, and travel back to the start where they merge together. This produces an interference pattern like the fringes formed when you fold a net curtain in two, with the exact pattern depending on the difference in distance that the two beams travel. If the path length of the "measurement" fibre varies, even by ten millionths of a millimetre, the pattern changes and the length variation can be calculated. This technique is called interferometry, and has been used for many years for precision measurement in physics laboratories. But optical fibres make it possible to take interferometry out of the lab to earn its living in the real world.

In recent years, such fibre-optic sensors have been used to measure strain in aeroplane wings and detect movements in large civil engineering projects such as bridges and dams, based on the same kinds of optical fibres as would be found in a modern optical communication system. But today Professor Jones described some very different kinds of fibres, custom designed for specific sensing tasks and promising a whole new range of high accuracy sensors.

The first special kind of fibre has multiple cores – not a useful development for optical communications, but ideal for measuring how something changes over short distances, by comparing the difference between adjacent cores. One simple but very useful application is to measure how a structure bends, where one side of the fibre stretches more than the other.

Professor Jones explained how special "gratings" can be inscribed with a laser beam along the length of a fibre, producing mirrors tuned to just one colour of light. After doing so, he can send white light up the fibre, from which the component colours will each be reflected at a different grating. "Taken together," explains Professor Jones, "this tells you exactly where the fibre is bending, by how much, and in which direction. That's enough to measure the strains on all parts of a wing or a mast just by using the light coming from a single glass fibre." Previously, such a measurement would have required hundreds or even thousands of electrical sensors. The new sensors are already being developed in collaboration with NASA to monitor flexible aerodynamic wings and, closer to home, for safety monitoring of tunnels by measuring changes in their shape.

The second class of specialist fibres are made of plastic. Glass fibres have their limits, and optical strain gauges could be used in many more situations if only the fibres were more resilient. Modern plastic and composite structures are excellent for saving weight, but need to be monitored for excessive stresses. For this application, plastic fibres are ideal, but only now are they being made sufficiently slender for interferometry.

Thirdly, in situations where communications fibres are still best, scientists can make them even more versatile by constructing tiny structures at their tips. In one such example, they use a powerful laser to drill a hole just thousandths of a millimetre wide in the end of the fibre and then cap it with a lightweight membrane. "These microsensors may be the fastest-reacting pressure sensors in the world," explains Professor Jones. "And they're so robust that we'll be using them to measure blast waves. In the current climate of increased terror threat, there's a huge demand for technology which could help to design bomb-proof buildings".

Professor Jones believes that fibre-optic sensors are becoming ever more useful, with applications in power generation, for air and sea guidance systems, and in food safety and medicine. The spread of this technology from the laboratory into everyday use has barely begun.

Professor Julian Jones is Professor of Engineering Optics and Head of the School of Engineering and Physical Sciences at Heriot-Watt University.

Source: Institute of Physics