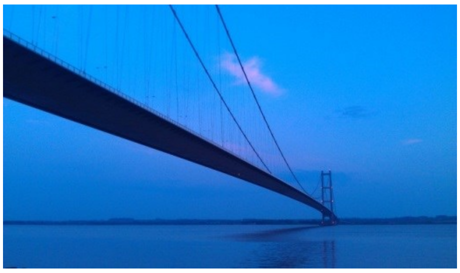
Summary of description of project context and objectives



Maintaining the structural integrity of safety critical constructions, such as bridges, becomes increasingly difficult as they age. A vital part is the periodic inspection for detecting degredation, such as fatigue cracks and corrosion that are not always visible to the typical manual and visual inspections alone, but may eventually lead to catastrophic failure. There are several aspects that need to be considered in periodic inspections using conventional techniques only; flaws may grow to failure between inspections, access to conduct the inspection may be poor and it may be difficult to determine the significance of any flaw that has been detected and decide whether failure is imminent or if it can be left until a more propitious time for repair.

There is therefore strong interest in replacing periodic inspections with full-time, continuous Structural Health Monitoring (SHM), with networks of sensors that are permanently installed on the structure and are sensitive to defect development. Where these structures are very large, wireless sensor networks offer significant benefits. Although there are many promising SHM technologies applicable to a variety of civil and defence infrastructure, most of them use expensive components, bulky equipment and have prohibitive power requirements, which prevent permanent, large-scale, installations of networked sensors across remote locations.

Such interest has led a consortium of small-to-medium sized enterprises to sponsor research with support from the European Union's FP7 research programme to develop a wireless sensor network technology for the SHM of bridges. The 2-year project which commenced in October 2011 is called 'Wi-Health'. The main objective of Wi-Health project is to develop technology for multi-purpose wireless networks that combine the Long Range Ultrasonic (LRU) and Acoustic Emission (AE) monitoring techniques in autonomously powered nodes for the detection of defect growth at damage-prone areas of bridges, such as welded plate structures. As the unprocessed data streams produced by these monitoring techniques require a high bandwidth, data processing at the node devices has been used to greatly reduce the bandwidth requirement of each node, which makes large numbers of wirelessly networked monitoring devices possible. Embedded software has been used to drive the structural health monitoring system for defect identification by incorporating the use of trend analysis and data processing.

Description of work performed and main results

At the beginning of the project, the consortium has identified the cases where the project would provide the most benefit towards resolving critical problems within the bridge industry. The consortium also tried to target problems that occur in other large engineering structures so that the developed technology would be applicable across industry. The developed sensor network is multi-purpose. The devices make use of existing commercially available sensors for ultrasonics and temperature sensing. The developed devices support both active and passive ultrasonic methods (LRU and AE respectively).

The approach used for monitoring with LRU involves a means of transmitting waves through a structure and receiving them after they have interacted with potential defects. The signals are interpreted to identify features of the signals that correspond to defects. AE is usually done with separate equipment with centralised electronics and sensors connected by very long cables. This approach requires the long cables to be very high quality, making it expensive. It also requires the use of very low noise amplifiers distributed with the sensors, which is also expensive. By using wireless technology, integrated ultrasonic techniques and having electronics distributed with the sensors, Wi-Health has produced technology with the potential to greatly reduce the cabling used in the SHM of large engineering structures in a way which can be cost effective for large scale use. In the second reporting period, an optimized sensor array was designed, built and tested, which could be used to monitor the inspection of the various bridge sections (with LRU and AE) with minimal sensor numbers. The project addressed all proposed areas for new developments and achieved major goals. This is mainly linked to the demonstration of the application of long term LRU based monitoring on large, representative plates in the laboratory. These plates were replicas of bridge components and defect detection trials with these parts demonstrated the developed LRU technique was capable of detecting the flaws as they developed. Such condition monitoring has great potential to increase understanding of the structural integrity of large engineering structures, increasing their service life and greatly reducing the risk of catastrophic failures. The construction of the wireless communication technology for medium and long range communications between nodes and also the base station; the conduit for information moving between the structure and the outside world has been completed and demonstrated. The technology is attractive because of its wide application, low cost, availability of hardware, proven mesh establishment and routing protocols and ability to communicate over long ranges, especially with a directional antenna.

A wind turbine together with solar panels were selected as the most appropriate energy sources for the Wi-Health system in order to develop a robust system suited to continuous operation. Such renewable energy sources reduce the need for power cables on structures undergoing SHM. The support for both wind and solar power makes the system flexible for application in a variety of locations throughout the world.

Expected final results and potential impacts

Bridge collapses arouse strong public concern. Most major collapses have resulted in significant loss of life and serious economic losses resulting from the interruption to transport and the need for reinstatement. Routine inspection can help detect developing flaws so that remedial action can be taken, but full-scale, regular inspection of large structures is often cost prohibitive and is often not done as frequently as it is desired. The Wi-Health project developed an advanced integrated system for Structural Health Monitoring (SHM) for bridges (and other large engineering structures), which could be used to reduce the need for inspection thus reducing the cost of maintenance and making structures safer. Several technological developments under Wi-Health have contributed to the development of this system.

An active long range ultrasonic method of monitoring welded structures for the presence of developing fatigue cracks and corrosion was developed. This method makes use of Ultrasonic Guided Waves by monitoring the changes to the way the sound is scattered by developing flaws. This method was trialled on the same geometry as sections of a real bridge and was shown to detect flaws (with characteristics similar to those of concern to industry) as they were introduced in the lab. Passive ultrasonic (Acoustic Emission) techniques have already been established for structures of this kind, but do not support Acoustic Emission between wirelessly connected sensors. Under Wi-Health this difficulty was overcome. A small scale array of ultrasonic sensors was shown to be effective for use in both the passive and active ultrasonic methods. By using sparsely distributed, multipurpose sensors, this demonstrated that a foot print of many square meters of a structure can be monitored with both techniques whilst using relatively few sensors.

Wireless methods of data transmission and device management (communication protocols) were designed and analysis within the project demonstrated that these methods had the potential to support a SHM network with potentially thousands of sensors.

Support for multiple methods of power (including by small-scale wind turbines and solar panels) was demonstrated, making it possible to power individual devices or small groups of devices autonomously.

Software for managing the sensor network and the database of monitoring data was developed. This was designed to allow control and oversight of the monitoring whilst it was on-going on. It was also designed to enable integration with other information systems.

These developments mean that for the first time a very large scale wirelessly integrated network of devices could be used to ultrasonically monitor for structural flaws (and make use of other parametric inputs such as temperature) whilst being managed in real-time from a single computer in a centrally organised way with the potential to be more cost effective than existing, more limited alternatives.

Wi-Health is collaboration between the following organisations:
TWI Ltd, Vermon S.A., Polkom Bodania, Tangent Technologies Ltd., Humber Bridge Board, Kingston Computer Consultancy Ltd, Feldman Enterpise Ltd, I.D.E.A.S. Ltd.

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The project website, www.wi-health.eu, presents introductions to all Wi-Health consortium members with links to their respective websites.