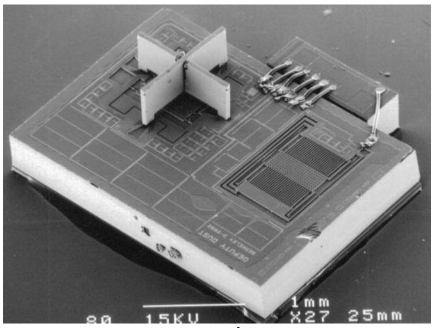
Transport Research Laboratory



"Smart dust"
BA Warneke - UC Berkeley (2003)

Use of micro-electro-mechanical systems and wireless sensor networks on road infrastructures

by J Iaquinta

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Use of micro-electro-mechanical systems and wireless sensor networks on road infrastructures

by J Iaquinta (TRL)

Prepared for: Project Record: **Potential contribution of nanotechnology in pavement engineering and traffic operation**

Client: **Transport Research Foundation (TRF)**
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Executive summary

This small project has been funded under TRF's Research Programme and focused on the use of micro-electromechanical systems and wireless sensor networks for applications in the fields of transportation and transportation infrastructures. The present document introduces these technologies, and examples of how they could facilitate data collection are provided for the purpose of illustration.

The use of micro-electromechanical systems and wireless sensor networks for data acquisition and monitoring purposes offers new perspectives to the engineer. Contrary to "standard" data collection systems which are primarily wired, the small size of these sensors along with the absence of wires connecting each device to its power supply and to a data processing unit, allows to address problems in a different way, more easily and at low cost. The ability to have many of these wireless sensors communicating with each other makes it possible to form a mesh network for monitoring large structures or areas.

This is still a new technology, therefore technical knowledge is required to understand a few basic principles (including notions of network functioning, power management, etc.), to choose the most appropriate devices for each situation and to make them to work. However, the assembly and operation themselves can be much simpler than those of traditional sensor systems.

Though, several issues still have to be explored, for example, to examine the application of "ready-to-use" devices (or work with manufacturers to adapt existing products), set-up demo sites to show that such devices can work out of the laboratory, assess the level of performance and reliability that can be achieved, sort out technical issues (with the communication, energy supply, housing, etc.).

It is finally recommended to initiate further discussions with experts in each field of application to clarify how the techniques could best be applied. This would also have the advantage of enhancing the potential benefits of such applications and bringing the new ideas to the attention of customers.

Abstract

The potential of nanotechnologies and micro-electromechanical systems (MEMS) has already been explored a few years ago in the frame of a research project for the Highways Agency. A very wide range of promising applications were then identified within pavement engineering and traffic operations, some of which were related to the use of Wireless Sensor Networks (WSN). The present work, funded under TRF's Research Programme, focused on this technology since it is believed that it can be widespread as an economic solution for large-scale monitoring applications. Essential principles related to wireless sensor networks, mesh networking, energy management and MEMS are discussed. An example of practical use of such instrumentation is presented and realistic applications of WSN are described.

1 Introduction

The use of electronic instruments for data-acquisition and monitoring is not, in itself, a new concept. For years researchers and technicians have relied on digital measurements of physical quantities as simple as temperature and as difficult to assess as humidity or acceleration. Yet, these early systems were primarily wired and the presence of wires connecting each sensor to its power supply and data processing unit has always been an issue. Other limitations were related to the cost of the computing equipment and technical knowledge required to assemble and operate even a simple system of sensors.

To give an idea of the complexity, instrumenting the three major bridges in Hong Kong, namely the Tsing Ma Bridge, Kap Shui Mun Bridge and Ting Kau Bridge, required over 1000 sensors, consumed 36km of copper cable and 14km of fibre optic cable, and the installation has taken over a year (Wang et al, 2007). In terms of the cost, the total price for instrumentation of the Tsing Ma suspension bridge alone, with a 600 channel structural monitoring system, was over $16 million (Lynch et al, 2003).

A large numbers of variables combined with the numerous places where it was possible to introduce errors have made large wired monitoring systems extremely difficult to install and manage (Bushman, 2004). With the development of Micro-Electro-Mechanical Systems (MEMS) the problem becomes more critical than ever: where is the point in using a tiny system if there is still a need for invasive cabling and power supply and data logger and storage and processing units?

Recent technological advances made it possible to envisage a future where a large number of low-power and inexpensive sensing devices can be densely embedded in the physical environment, working together in a wireless network (Krishnamachari, 2006). Such Wireless Sensor Networks (WSN) are the key to gathering data and providing a link between the real physical world and the virtual world of information technology. What is new is that it can be achieved easily, with reduced cost and setup time for layouts requiring widespread placement.

Deployments can simply be replacements for wired systems but WSN also open the way to applications that were not conceivable so far with traditional instrumentation. This for instance gave rise to the notion of “smart dust” (Akyildiz et al, 2002): miniature self-contained systems that can be scattered in very large numbers to keep watch on just about anything, from measuring vibration and light levels, to tasks more demanding such as taking pictures or analyzing chemicals (see the picture in the front page of this document).

Although the systems currently available on the market are still far bigger than just dust-sized instrumentation, WSN could be widely implemented in transportation application fields. Typically a wireless deployment solution would be appropriate for monitoring civil infrastructures (Liu, 2008), hazardous roadway surface condition (Pei et al, 2007), slopes prone to failure (Reid et al, 1998) and shallow landslides during heavy rainfall (Antronico et al, 2007), roadside pollution (Cao et al, 2008), water flow in drains and pipelines (Stoianov et al, 2007), flooding (Kuang et al, 2008), etc. Wireless sensor networks could also useful for traffic management, for instance to detect vehicles moving/stationary in fog, ensure a safe inter-vehicle distance, generate alerts in the case of black ice on road, etc.

As often happens for new technologies, with nearly no previous experience in-house, there are questions to answer and issues to be aware of. Therefore the present paper does not seek to outline the state of the art in wireless technology or to provide an exhaustive list of MEMS devices, mainly because in this area things are changing extremely quickly. Instead it seemed useful to get an understanding of the existing technology, how it can be taken benefit from advances in sensing and data processing as well as innovations in the field of wireless data transfer.

The first section of the document presents basic principles related to wireless sensor networks, mesh networking, energy management and MEMS. The second section gives an example where the use of a Zigbee sensor quickly provided an answer to a problem that would have otherwise required much more preparation with a wired system. A few unusual applications are also described where the use of the new technology would be relevant on road infrastructures.

2 Wireless sensor network

2.1 Definition

A Wireless Sensor Network consists of spatially distributed autonomous devices (nodes) using sensors to cooperatively monitor physical or environmental conditions such as temperature, humidity, acceleration, etc.

In addition to one or more sensors, and if needed an Analogue to Digital Converter (ADC), each node typically includes (Figure 1):

- a radio transceiver (for communications);
- a micro-controller (for data processing);
- a memory (for data storage);
- a power supply (or energy scavenging system).

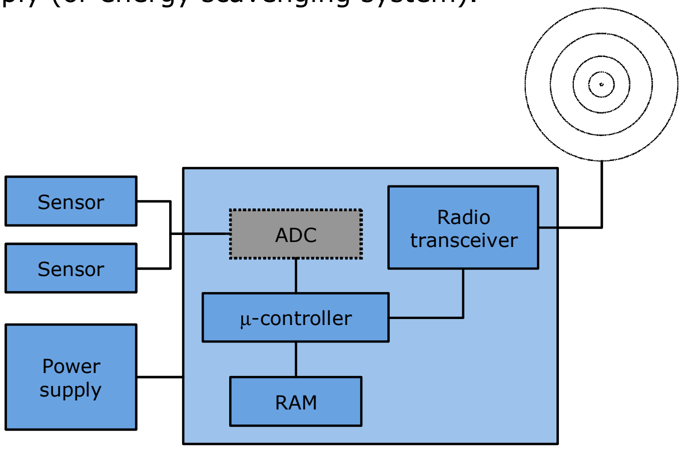


Figure 1: Example of platform for wireless monitoring applications

Depending on the applications the choice of hardware and firmware is a function of the energy consumption, radiated power, data rate, number of devices in the network, robustness, expected range, data protection and cost (Lee et al, 2007). For low data rate wireless networks, which can typically be implemented for monitoring applications with a large number of nodes having an extended range, devices based on the ZigBee protocol (named from the zig-zag path of bees between flowers) seem to provide an appropriate level of redundancy and reliability.

If possible such a sensor network will have to require no (or a minimal) maintenance, be self-powered (from a few minutes up to several years, depending on the duration of the project), be reliable, dynamically adapt its topology and if needed be able to cope with node failures. The following paragraphs introduce mesh networking and energy management issues.

2.2 Mesh networking

Mesh networking is a way to route data, voice and instructions between nodes. It allows for continuous connections and reconfiguration around broken or blocked paths by "hopping" from node to node until the destination is reached. The component parts can all connect to each other via multiple hops. Mesh networks are self-healing in that the network can still operate even when a node breaks down or a connection goes bad. As a result, a very reliable network is formed and this makes it an ideal candidate for most monitoring applications.

There are only three general types of node in a ZigBee network (Figure 2):

- the coordinator is mainly needed at system initialisation, to select the frequency channel to be used by the network, start the network and allow other devices to connect to it (that is, to join the network);
- end devices are always located at the extremities of the network and send/receive messages but cannot relay messages and cannot allow other nodes to connect to the network through them;
- routers whose main tasks are to relay messages from one node to another (and to the coordinator) and to allow new nodes to connect to the network.

End devices can be battery-powered and, when not transmitting or receiving, can sleep in order to save energy. However, the coordinator and the routers cannot sleep.

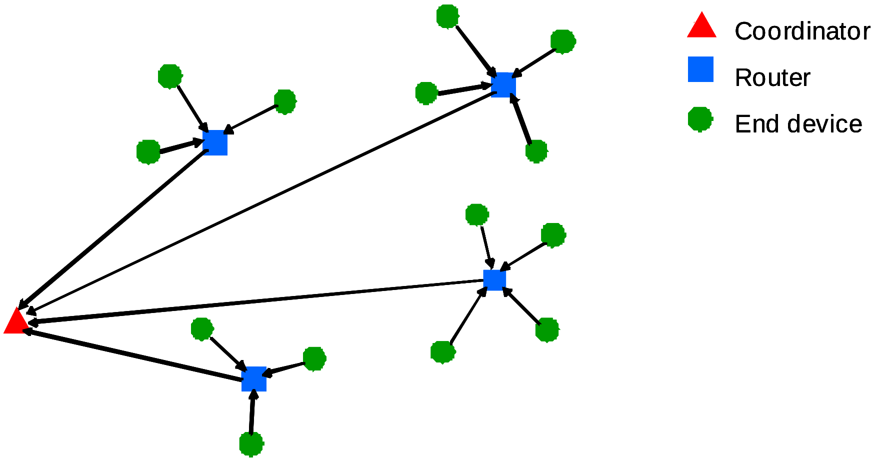


Figure 2: Example of mesh network layout with one coordinator, four routers and many end devices

2.3 Energy management

With wireless technology energy management is always an issue and so it is for a WSN. However energy consumption can be minimized by choosing the right low-consumption component combination (in particular the radio transceiver and micro-controller) and supply can now take different forms.

2.3.1 Power consumption

2.3.1.1 Radio transceiver

The radio transceivers of ZigBee devices have been developed in order to maximize the reception quality. The drawback is that they consume nearly as much power in receive mode as transmit mode, typically 27mA for the CC2480 from Texas Instruments (Figure 3). The only way to significantly reduce power is to “negotiate” sleeping periods.

Figure 3: Z-Accel demonstration board with the CC2480 ZigBee 2.4 GHz network processor [from www.ti.com]

A ZigBee device may sleep (in which case it typically consumes less then 1μA) until it has a reason to transmit. However, in this state it cannot forward messages on behalf of other devices. The availability of mains-powered routers does, however, provide the possibility of an extensive network where most devices may be battery powered for several years, if not for the shelf life of the battery.

2.3.1.2 Micro-controller

The operation of the Micro-Controller Unit (MCU) takes energy and therefore a short wake-up time as well as low operating and sleep currents are preferred. Some ultra low power micro-controllers have been especially designed with this in mind, for instance the high-performance HCS08 family of 8-bit micro-controller units from Freescale Semiconductor (Figure 4) or the MSP430 family 16-bit micro-processor platform (Wines and Braathen, 2008).

Figure 4: MC9S08QG8 8-bit microcontroller unit on a Z-STAR2 demonstration board [from www.freescale.com]

2.3.2 Energy supply

It is always difficult to calculate the exact lifetime of a system since there are lots of factors that may affect power consumption (transmission period, pool period, traffic on the channel, interference, etc.). However, for instance, if configured to transmit one packet every 10s the board shown on Figure 3 would operate for about 4 years with two AAA batteries.

Other types of energy storage solutions would potentially expand the lifetime, for instance using ultra-capacitors with low Equivalent Serial Resistance and nano-porous electrodes (Figure 5a) or micro fuel cells with nano-engineered Proton Exchange Membranes (Figure 5b). Energy harvesting technique could also be considered for a refill to virtually make the system last as long as the energy source is available.

a) 

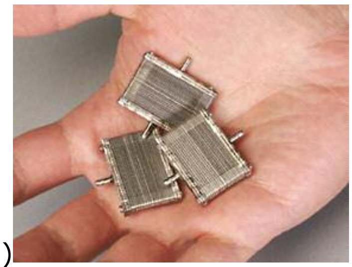
b) 

Figure 5: a) ultra-capacitor offering a capacitance of 10F [from www.maxwell.com] , and b) micro fuel cells weighting 14g and providing 200mW under 5V [from www.angstrompower.com]

2.3.2.1 Batteries

A battery is a device that transforms chemical energy into electric energy. Batteries are broadly classified into primary and secondary. Primary batteries are the most common and are designed as single use batteries, to be discarded or recycled after they run out. They have very high impedance which translates into long life energy storage for low current loads. Secondary batteries are designed to be recharged. For most of these batteries very deep discharges result in a shorter cycle life, whereas shorter discharges result in long cycle life.

2.3.2.2 Ultra-capacitors

Ultra-capacitors (also called super-capacitors or Electric Double Layer capacitors) are very high surface area activated carbon capacitors that use a molecule-thin layer of electrolyte, rather than a manufactured sheet of material, as the dielectric to separate charge. The ultra-capacitor resembles a regular capacitor except that it offers very high capacitance in a small package. Energy storage is by means of static charge rather than of an electro-chemical process inherent in the battery (Figure 5a).

Contrary to batteries, which have a high energy density but a low power density, ultra-capacitors have a relatively high power density, but low energy density. This means that ultra-capacitors cannot store as much energy, but the rate of energy transfer out of ultra-capacitors is much greater than that of a battery. Ultra-capacitors can also cope with changing currents and hence be charged from very intermittent sources whereas charging a battery requires a constant current.

2.3.2.3 Micro fuel cells

Fuel cells are electrochemical devices like batteries that convert the chemical energy of a fuel directly and very efficiently into electricity (DC) and heat, thus doing away with combustion. Unlike a battery, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat as long as fuel is supplied as opposed to the limited internal energy storage capacity of a battery. New developments like the small Direct Methanol Fuel Cell (DMFC) do not require extraneous control equipment (pump or cooling) which makes them practical for portable applications.

Fuel cells range in size from hand-held systems to megawatt power stations. Most large fuel cells operate at high temperatures (200°C to 1000°C) but the Proton-Exchange Membrane Fuel Cell (PEMFC) may be able to operate at room temperature (Figure 5b). The service life of fuel cells is such that they were approved for use in space vehicles (Apollo missions, Space Shuttle program) and are considered for applications requiring more than 40,000 hours of reliable operation.

2.3.2.4 Energy harvesting

Energy harvesting could also be a solution in certain applications where it would be possible to exploit solar concentrators and solar cells, micro turbines, piezo-electric generators, magnetostrictive transformation, waste heat conversion, vibrations, etc. (Iaquinta and Wright, 2007). Devices to harvest energy from ambient sources are still not powerful enough to provide stable energy, but in specific environmental conditions they can offer a very smart but rather expensive solution. For instance energy harvesters can be tuned to the exact frequency of the vibration induced by a helicopter engine or rotor blades to generate electrical power (Figure 6) whereas vibrations on a structure are more low frequency and broad band which makes them much more difficult to exploit efficiently.

Figure 6: PMG27 a vibration energy-harvester for the aerospace industry priced at ≈£1000 [from www.perpetuum.co.uk]

Solar harvesting is still, to date, the most effective and easy way of extracting energy from low grade sources. However, this can only provide about 15mW/cm^2 (outdoor) and it is highly dependent upon the intensity and duration of the possible exposure.

2.3.3 Summary

Table 1 gives a brief summary of some critical properties of ultra-capacitor, micro fuel cell and battery technologies. Because there are so many types with widely different characteristics, values are shown as an indicative range.

Ultra-capacitors offer the highest power density (i.e., power per unit of mass) and micro fuel cells exhibit high energy densities (amount of energy stored per unit mass). As a compromise fuel cells can be used in tandem with ultra-capacitors (or even batteries) to provide a high-energy, high-power combination.

In all cases, a simple onboard voltage sensor (already installed on most of the ZigBee devices) would allow a maintenance alert to be generated when the power supply reached a critical level.

	Ultra-capacitor	Micro fuel cell	Secondary battery
Charge and discharge time	ms to s	Instant charge 10 to 300h	1 to 10h
Operating temperature	-40 to +85°C	5 to +90°C	-20 to +65°C
Operating voltage	2.3 to 3V per cell	0.6V per cell	1.25 to 4.2V per cell
Life	> 30,000h	1500 to 10,000h	150 to 1500 cycles
Power density	10 to 100kW/kg	0.001 to 0.1kW/kg	0.005 to 0.4kW/kg
Energy density	1 to 5Wh/kg	300 to 3000Wh/kg	10 to 500Wh/kg

Table 1: Comparison chart for ultra-capacitor, micro fuel cell and battery technologies

2.4 Micro-Electro-Mechanical Systems

Nano-mechanical machines and devices are currently in an early phase of development, and many are still in conceptual stages. Therefore, although Micro-Electro-Mechanical Systems (MEMS) and Micro-Opto-Electro-Mechanical Systems (MOEMS) do not “technically” fall under the subject of nanotechnology, they represent a much more mature technology and are already available.

One of the first MEMS produced (by Analogue Device, a pioneer in micro-machines) was able to sense sudden accelerations and was used to initiate airbag deployment in automobiles. MEMS are by now very well developed and are available for most sensing applications in wireless networks (Lewis, 2004).

In general terms, a “sensor” is a transducer that transforms some physical process into an electrical signal, which can be measured for instance by a digital processor. Broadly (Bao, 2005) MEMS embrace mechanical, electro-magnetic, thermal and chemical sensors:

- mechanical sensors include those that rely on direct physical contact
    - the piezo-resistive effect converts an applied strain to a change in resistance that can be sensed using electronic circuits such as the Wheatstone bridge

- the piezo-electric effect converts an applied stress (force) to a charge separation or potential difference. The piezoelectric effect is reversible, so that a change in voltage also generates a force and a corresponding change in thickness, therefore the same device can be both a sensor and an actuator
- capacitive sensors typically have one fixed plate and one movable plate. When a force is applied to the movable plate, the resulting displacement is related to a change in capacitance that can be detected using a variety of electric circuits and converted to a voltage or current change

- magnetic and electromagnetic sensors do not require direct physical contact and are useful for detecting proximity effects
    - the Hall effect relies on the fact that the Lorentz Force deflects flowing charge carriers in a direction perpendicular to both their direction of flow and an applied magnetic field (i.e. vector cross product)
    - the magneto-resistive effect is a related phenomenon depending on the fact that the conductivity varies as the square of the applied flux density
    - magnetic field sensors can be used to detect the remote presence of metallic objects
- thermal sensors are a family of sensors used to measure temperature or heat flux
    - thermo-mechanical transduction is used for temperature sensing and regulation. On changes in temperature all materials exhibit (linear) thermal expansion so that one can fabricate a strip of two joined materials with different thermal expansions and the radius of curvature of this thermal bimorph depends on the temperature change
    - thermo-resistive effects are based on the fact that the resistance of some materials changes with temperature
    - thermo-couples are based on the thermoelectric Seebeck effect, whereby if a circuit consists of two different materials joined together at each end, with one junction hotter than the other, a current flows in the circuit and this generates a Seebeck voltage
- chemical transducers cover a very wide range of devices that interact with solids, liquids, and gases of all types. Potential applications include environmental monitoring. Effective use has been shown for sensing NOx (from pollution), COx, SOx, and others
    - chemi-resistors have two inter-digitated finger electrodes coated with specialized chemical coatings that change their resistance when exposed to certain chemical challenge agents
    - metal-oxide gas sensors rely on the fact that adsorption of gases onto certain semiconductors greatly changes their resistivity.

3 Examples of application

There are situations where the use of wired instrumentations is really impractical and where wireless sensors can provide a quick and easy answer; An example is described below. Beside the implementation of wireless sensor networks in replacement of "equivalent" wired systems (for structural health monitoring, monitoring of landslides, monitoring of cable strayed bridges, etc.), the few examples of applications presented hereafter would be worth further investigations.

3.1 Practical use of a Zigbee device

In the context of a project related to the characterisation of the rolling resistance of a truck wheel on different types of pavements, experiments are being carried out in TRL's Pavement Test Facility (PTF). Instrumentation has been developed for the measurement of the various parameters needed to calculate the coefficient of rolling resistance. All the sensors used are wired and required the installation of digital and analogue logger units, shown in Figure 7, as well as long lengths of cables to bring the data to a PC for storage and later processing.

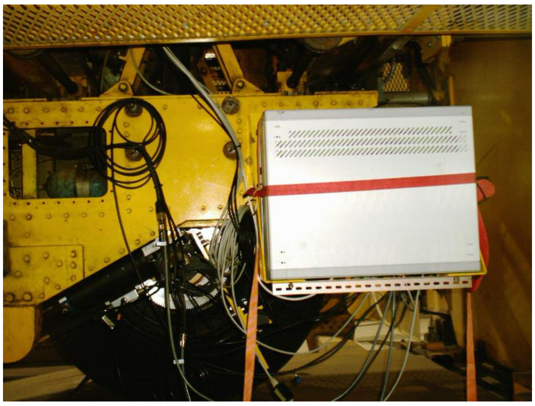


Figure 7: Data logger for the experiments carried out in the PTF

During pre-trials it was found that signal noise with a frequency about 8Hz introduced unwanted disturbances to the measurements. It was thought that the source of this noise was the wire rope which serves to move the whole carriage of the PFT back and forth. In order to validate (or invalidate) this hypothesis, a wireless accelerometer (Figure 8) that could be placed at different places in the PTF, was used to measure accelerations in a range of +/-1.5g at up to 200 samples per second. An example of data obtained with the accelerometer attached on the rope is displayed in Figure 9.

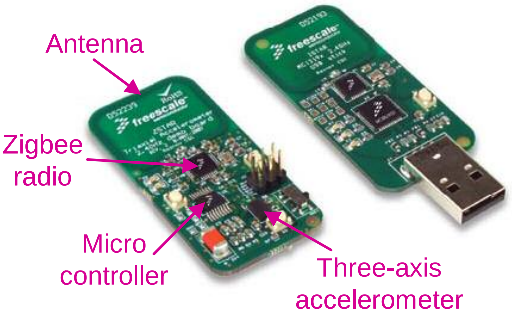


Figure 8: Triple-axis accelerometer board (with a small BR2032 3V battery underneath) and USB (coordinator) board [model RD3473MMA7360L from www.freescale.com]

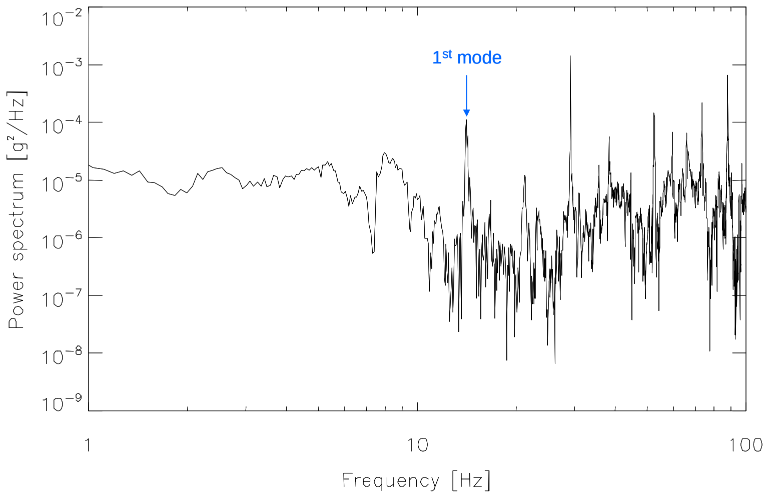


Figure 9: Power spectrum derived from the signal provided by the wireless accelerometer attached on the rope of the PTF

The power spectrum[1] (obtained from measurements of acceleration along one of the axis of the accelerometer after having excited the rope) shows how the power of the signal is distributed with frequency. In this case the first mode of vibration of the rope is about 14Hz which at least 6Hz higher than the frequency of the noise that affected the data, therefore it is unlikely that this is the source of the unwanted signal noise mentioned earlier.

The whole experiment with the accelerometer took a few minutes and allowed access to hidden recesses without wiring (that would otherwise have disturbed the measurements). This example shows how easy it can be to use a wireless device and quickly get answers to specific problems with off-the-shelf products.

3.2 Pavement surface temperature

Whether or not road or bridge frost will form depends primarily on the pavement temperature and dew point temperature. For winter maintenance it would be useful for the stakeholder to have, in real-time, an accurate "picture" of the pavement surface temperature and the corresponding dew point temperature on sensitive sections of the network or principal bridges.

MEMS surface sensors (Figure 10) would be in place 24 hours a day, all year-round, and provide information for decision-makers (through a Road Weather Information System) to plan anti-icing operations prior to the dispatching of personnel or materials and before surface temperatures reach the freezing point.

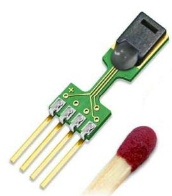


Figure 10: High-precision capacitive humidity and temperature sensor SHT75 having precise dew point calculation capabilities [from www.sensirion.com]

There are already temperature sensors and meteorological stations on the road network. Their implantation has generally been carefully arranged (typically based on historical data, information about cold spots and thermal maps). However, these sensors are not

[1] *Defined as the squared value of the module of the Fourrier transform of the signal.*

deployed in large numbers and may not provide a detailed picture of the condition of the network, especially in the case of unexpected event.

This could be achieved with wireless sensors (Zigbee end devices) installed at regular intervals on the pavement and a few routers (possibly mains-powered) to relay the information. This would for instance help in deciding when to send trucks for de-icing and display messages on Variable Message signs to warn road users of the potential danger.

In addition to temperature sensors, the devices could include something to assess the surface moisture, electrochemical conductivity (related to the amount of de-icing chemical on the surface), or combine parameters including for instance thermal conductivity, electrochemical polarization and surface capacitance to determine whether water, snow, or ice is on the pavement.

3.3 Safe inter-vehicle distance

To help drivers ensure a safe inter-vehicle distance small devices with a MEMS anisotropic magneto-resistive sensor (Figure 11) could be used to detect the passage of a vehicle. If the following vehicle arrives less than for instance 2s after, there could be warning announcement on a nearby Variable Message Sign (to display something like "Keep your safe distance"). The sensor could be installed in a road stud between dashes on a lane line or in the middle of the traffic lane. Data exchanges would be wireless, possibly bi-directional so that the time interval is adjustable remotely. The system could also provide real-time data (vehicle counts, etc.) to a traffic management centre.

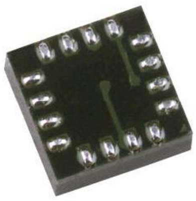


Figure 11: Miniature three-axis surface mount sensor array HMC1043 designed for low magnetic field sensing [from www.ssec.honeywell.com]

Messages could be directly sent to the driver of a car equipped with the appropriate receiver using the 5.85-5.92GHz band recently made available by the European Commission for the forthcoming IEEE 802.11p standard for Wireless Access for the Vehicular Environment (WAVE).

Note that a system using 3 cameras has been trialled on the A10 near Orleans in France to warn drivers that are too close from the preceding vehicle and display their plate number on a VMS. However this system does not work in adverse weather and poor visibility conditions (heavy rain, snow, fog, etc.), which is precisely where it would be the most useful for safety, whereas the system presented here would not be affected.

3.4 Stationary vehicles ahead

The same anisotropic magneto-resistive sensor as that mentioned in section 3.3 can be used for robust real time vehicle detection in traffic surveillance systems. Besides achieving superior performances than the usual inductive loop detectors such MEMS offer a flexible and cost-effective solution to be deployed on a large scale. In addition, using these small easily installed wireless sensors eliminates drawbacks related to disruption of traffic for installation and repair, failures caused by traffic stress and resurfacing, and sensitivity dependence on temperature and vehicle speed (Cheung and Varaiya, 2007).

Since almost all vehicles have significant amounts of ferrous metals in their chassis (iron, steel, nickel, cobalt, etc.), the magnetic field disturbance created by a vehicle is sufficient to be detected by a magnetic sensor. The sensor would therefore detect the presence of stationary vehicles (accident, broken down, etc.) that represent a real danger for other vehicles. Because different types of vehicles have different magnetic signatures, it would also be possible to remotely report the size of the stationary vehicle. This would be particularly relevant to have for instance on sections of motorway or bridges prone to fog (next to rivers or water areas) to provide early alerts to other road users and lessen accidents.

3.5 Roadside air quality monitoring

Today's air monitoring procedure usually requires the collection of air samples at remote locations, which then have to be returned to a laboratory for analysis. The air quality can also be monitored with systems like that pictured on Figure 12a which have detectors for volatile organic compounds, temperature, humidity, carbon dioxide, toxic gases, etc. With this system, communications with a base station are achieved using a RF transceiver that has a range of a few km.

Due to their cost (about £5000) such devices cannot be deployed in large numbers. This means that the information that they transmit back to the base station only provides a very coarse picture on the air quality on the network. They also have to be installed near mains power supply to ensure that they operate over a long period of time; further increasing the cost of deployment and reducing the possible sites potentially monitored.

a) 

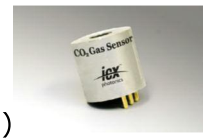
b) 

Figure 12: a) Air quality sensor AreaRAE IAQ [from www.raesystems.com], and b) highly integrated SensorChip CO_2 sensor [from photonics.icxt.com]

Integrating MEMS chemical sensors like that of Figure 12b in wireless sensor nodes would lead to a new approach to monitoring air quality that could be analyzed and recorded in-situ. They could be deployed in large numbers, as they would be much cheaper, and the cost of deployment of a WSN would be negligible as they would not have to be wired and/or mains-powered. The increased density of sensors would provide a much more accurate picture of the spatial distribution and concentration of the gases monitored.

4 Conclusion

There are all sorts of Micro-Electro-Mechanical Systems that can be installed in road infrastructures for monitoring purposes and data collection. Such devices can be operated in a wired mode or in a wireless mode (if the data rate is not too high) but wireless is really the key to gathering the information needed by smart environments. Wireless devices can be part of a mesh network (Zigbee, for instance) and communicate with each other or simply send information to a remote station.

With wireless devices to be used during long periods of time one of the main issues will be related to energy supply. This can be solved using batteries (for a few months/years, depending on the consumption), energy harvesting systems (depending on the location of the nodes there may be options to exploit sunlight, waste heat, vibrations, etc.), ultra-capacitors (for intermittent energy sources), micro fuel cells, and probably a combination of all these techniques.

Wireless sensors can sometimes be used as a replacement for (existing) wired systems or for applications that were not even envisaged before due to technical issues (size, access, cabling, etc.) or economic barriers. Different technologies can be selected based, amongst others, on the expected power consumption, communication range, bandwidth, reliability, need for encryption and requirements in terms of synchronization and real-time data delivery. Robust software design is also essential to optimise duty cycles (i.e., sleep/wake-up/activity of individual nodes) for long life wireless networks.

In this document the basic principles of operation of Wireless Sensor Networks have been presented and examples of realistic applications possible with commercial off-the-shelf devices have been given. Also the main message is probably that the advent of monitoring technologies requiring neither extensive support equipment, nor technical knowledge by the user, offers no less than a fundamental change in the way instrumentation has to be seen.

5 Recommendations and way forward

This work has shown that the use of Micro-Electro-Mechanical Systems and Wireless Sensor Networks, either as an alternative to "standard" instrumentation or for completely novel applications in the Infrastructure field, would be worth investigating further. Examples of such applications are presented in this document for the purpose of illustration, but future discussions with experts in each field of use would help clarify how the techniques could best be applied. This would also have the advantage of enhancing the potential benefits of such applications to the attention of customers.

Such consultations could not be achieved in this project because of the limited time and budget allocated. However, we would recommend that the following issues be explored, for example, examine the application of "ready-to-use" devices (or work with manufacturers to adapt existing products), set-up demo sites to show that such devices can work out of the laboratory, assess the level of performance and reliability that can be achieved, sort out technical issues (with the communication, energy supply, housing, etc.).

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