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Australian Communications and Media Authority

Sensing and monitoring
Recent developments

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Executive summary

This report explores developments in information and communications technology (ICT) that support the collection, connection and analysis of data through sensing and monitoring. Sensors are parts of all machines that gather data and have an integral role in subsequent processing and transport of data. Monitoring is a process that observes a state in time or tracks changes in data sets to derive information. Together, sensing and monitoring provide a mechanism for harvesting digital data. This growth in digital data is being used to drive changes in production and distribution processes and the reach of services in the Australian economy.

Sensor developments in miniaturisation and the integration of sensors into intelligent devices and systems have increased the capacity to measure, analyse and aggregate data at a very localised level. Built on the increasing capabilities of fixed-access and wireless networks, smart sensor developments allow the collection of raw data, which is processed into information and conveyed via a network connection. Data processing capabilities have also been streamlined and automated through the use of data centres and pattern recognition processes that allow near real-time data mining and analysis. Using the infrastructure of the internet and machine-to-machine communications has allowed the connection of more devices and transfer of more information not directly controlled or monitored by humans.

The exponential increase in the number of devices with digital connectivity will require new connection and management processes. Addressing and identifying a population of potentially tens of billions of devices requires reliable, scalable and flexible systems to work between industry entities and consumers. The combination of these technology developments means that information is now gathered from more human and machine-based sources, and analysed and disseminated than ever before.

Information harvesting through sensing and monitoring is increasingly pervasive in many aspects of day-to-day life and is being used to drive changes in life-supporting sectors such as food, health, energy, environment, and entertainment and social engagement.

Identity management of millions of autonomous mobile sensor devices in a global environment presents challenges for sensor network operators and device life-cycle management. Dealing with ‘smart junk’, or the accumulation of lost or rogue devices without a traceable identity, is one of the challenges in managing device and data growth. Trusted relationships between consumers and industry will need to be extended to devices in this environment.

Data ownership, privacy, longevity of access and use are all potential issues in the provision of services to consumers in a smart digital economy. Consumers are also becoming increasingly aware of invasions to privacy through direct harvesting of information by application and service providers.

While sensing and monitoring data may empower people to make better decisions in real time, if information systems are not transparent and understood by citizens these decisions may be regarded as coerced rather than empowering. The ACMA will continue to monitor activities in the harvesting and use of information by services and applications.

Introduction

Humans have five basic senses—hearing, sight, touch, smell and taste correspond to the primary biological sensors, which are the ear, eye, skin, nose and tongue respectively. Using these sensors, humans are able to make observations, accumulate data and process it into usable information. However, built-in biological sensors have practical limitations of data range and type of observation, and they are not suitable for particular measurements. For instance, it is possible for an individual to make a relatively coarse temperature observation about their immediate surroundings, but biological sensors cannot make remote accurate temperature observations over a period of time in harsh environments.

In comparison, man-made sensors measure characteristics of real-world physical environments and convert them into raw data, which can be processed into information that may be used or kept digitally for later access and analysis. Monitoring is the process by which raw data is handled and further processed. Together, sensing and monitoring provide the mechanism for the harvesting of digital data.

Advances in information and communications technology (ICT), including the digitisation of information, mean that more information is now gathered, disseminated, analysed and stored than ever before. The growth of available information can provide valuable knowledge of the broader and immediate environments, and consequently the ability of individuals and businesses to exert control and influence over their environment. Technology developments in sensing and monitoring continue to drive process efficiencies, improvements in data quality and increased relevance of the derived information.

While the information revolution can potentially empower both organisations and individuals, it is also creating a pervasive environment that is increasingly less private, shrouded in technology, and raising questions about ownership and use of gathered information.

This report focuses on the underlying technology capabilities that support the harvesting of information through sensing and monitoring. It examines the use of sensing and monitoring developments across particular industry sectors of the digital economy, and looks at some potential implications of digital sensing and monitoring capabilities for users.

Methodology

This report draws on desktop research, information collection and analysis over the past year, focusing on emerging technological developments and trends in sensing, data acquisition and analysis in the developing digital economy. It contributes to work the ACMA is undertaking to inform its understanding of the operation of regulation in the communications and media industries, and as part of its statutory responsibilities to be informed and provide advice on technology developments and service trends. The ACMA welcomes feedback on this work.

Sensing and the digital data harvest

This chapter examines recent developments in technology capabilities across each of the core processes involved in sensing and monitoring—data collection, infrastructure connectivity, and data mining and analysis. It also looks at how sensing and monitoring processes are evolving in ways that no longer require human intervention, using the communications infrastructure of the internet through the 'internet of things' and machine-to-machine communications using mobile and internet-based technologies.

Collecting data

Sensors are fundamental elements of all machines that gather data, require feedback for their operation or are required to provide a Human Machine Interface (HMI). Purpose-specific sensors that are observable by instruments have been developed to enhance the scope and range of measurements. Electronic sensors based on semiconductor devices have been integrated with computers and communications networks to provide useful information-gathering solutions.

Technological developments in materials and electronics have led to the miniaturisation and integration of sensors into intelligent devices and systems that not only measure and analyse but also act on the resultant information. Intelligent sensors can also consolidate observations, and aggregate and analyse data locally to conserve downstream communications and analysis resources. Today, autonomous and connected sensors are able to selectively sample and measure many physical properties such as temperature, force, pressure, flow, position, and light intensity without impacting on the properties being measured.[1]

Sensors are generally part of a more comprehensive monitoring or data acquisition system that conditions, processes, converts and transports data. Monitoring is a process that observes a state in time or tracks changes in states over time. Observations may be made by humans or sensor-based instruments to form data sets from which information can be derived. Monitoring is governed by sensor functionality and the data analysis requirements, effectively bridging the two processes of sensing and analysis.

The application of monitoring plays an important role in collecting sufficient relevant information to achieve the desired outcomes of the process. Some monitoring systems are required to make observations from multiple remote and dispersed sensors that in turn require a single communications network path to transport individual sensor data to a point of aggregation and analysis. Where multiple sensors are concentrated over a smaller area, an underlying sensor–mesh network may be used to aggregate data prior to data transport over a communications network. The frequency and accuracy of sensor observations may also determine monitoring system design and particularly the proportion of resources that are sensor-, communications- and analysis-based.

Sensors can also be connected to actuators that translate information from the digital world into actions in the real world. For example, an integrated device may measure temperature, send digitised observations to a central point for analysis and receive information used to control a heater or cooler. This feedback process between sensors

[1] W. Kester, Analog Devices Inc., *Section 1 Introduction*, www.analog.com/static/imported-files/seminars_webcasts/576429268sscsect1.PDF.

and actuators can be performed locally in a programmable device or remotely over a communications network.

The integration of sensors, actuators, monitoring and analysis not only increases functionality but provides efficiencies in power consumption and physical footprint.

Miniaturised intelligent sensors are used in an increasing amount of applications from a range of devices such as cameras, cellular handsets, medical imaging equipment, and video and audio devices.[2] Micro-electronic-mechanical (MEM) devices are emerging as integrated device solutions. MEMs differ from conventional microchips in that they have built-in mechanical functions that allow them to act as both sensors and actuators.[3] Mechanical actuators extend the functionality of sensors by enabling a response with force. For example, MEM devices are used in cameras to compensate for 'shake' by adding a gyroscope and data conversion technology to prevent blurred photographic images.

The manufacture and embedding of smaller sensors into products is becoming a high-growth industry. According to Data Beans Inc., 'Sensors and MEMS can be considered a high-growth industry and is expected to increase penetration in automobiles, computers, and most significantly, portable products such as media players, tablet PCs, and smartphones.'[4]

Connecting data

Sensors require a network of interconnecting infrastructure to communicate and process the information required for services and monitoring applications. The availability of fixed-access and wireless mobile networks has guided the evolution of sensing by providing bidirectional connectivity for associated monitoring and control. Third-party integrators dominate systems development to provide novel and fragmented solutions across different industry sectors. These solutions tend to be dedicated, proprietary in nature and lacking interoperability.

The International Telecommunications Union—Telecommunications Standardisation Sector (ITU-T) conducts a watching brief in sensor networks as a candidate for standardisation work within the ITU. This work is useful in describing the complexities of sensing and monitoring networks. Figure 1 shows the layered components for what the ITU-T has described as the ubiquitous sensor network (USN).[5] These components are:

> sensor network—comprising sensors and an independent power source such as a battery or solar source

> USN access network—intermediary or 'sink nodes' collecting information from a group of sensors and facilitating communication with a control centre or external entities

[2]Analog Devices Inc., *It's An Analog World, How Analog Engineers Bring Digital Designs to Life*, www.analog.com/en/other-products/sampletrack-and-hold-amplifiers/products/CU_rr_Its_an_analog_world/fca.html, retrieved 14 June 2011.

[3] H. Wisniowski, Analog Devices Inc., *Analog Devices puts Micromachines in Motion*, www.analog.com/zh/mems-sensors/inertial-sensors/adxl103/products/technical-articles/CU_ta_Analog_Devices_Puts_Micromachines_In_Motion/resources/fca.html, retrieved 14 June 2011.

[4] Databeans, *2011 Sensors and MEMS*, Abstract, March 2011, www.databeans.net/products/2011_reports/re_11osdm_sensorsmems.php, retrieved 22 March 2011.

[5] International Telecommunications Union – Telecommunications (ITU-T), *Ubiquitous Sensor Networks (USN), ITU-T Technology Watching Brief Report Series, No. 4*, (February 2008), www.itu.int/dms_pub/itu-t/oth/23/01/T23010000040001PDFE.pdf, retrieved 14 June 2011.

> network infrastructure—likely to be based on a next-generation network (NGN)
> USN middleware—software for collecting and processing data
> USN applications platform—a technology platform to enable the effective use of a USN in a particular industrial sector or application.

Figure 1 ITU USN model

Source: ITU.

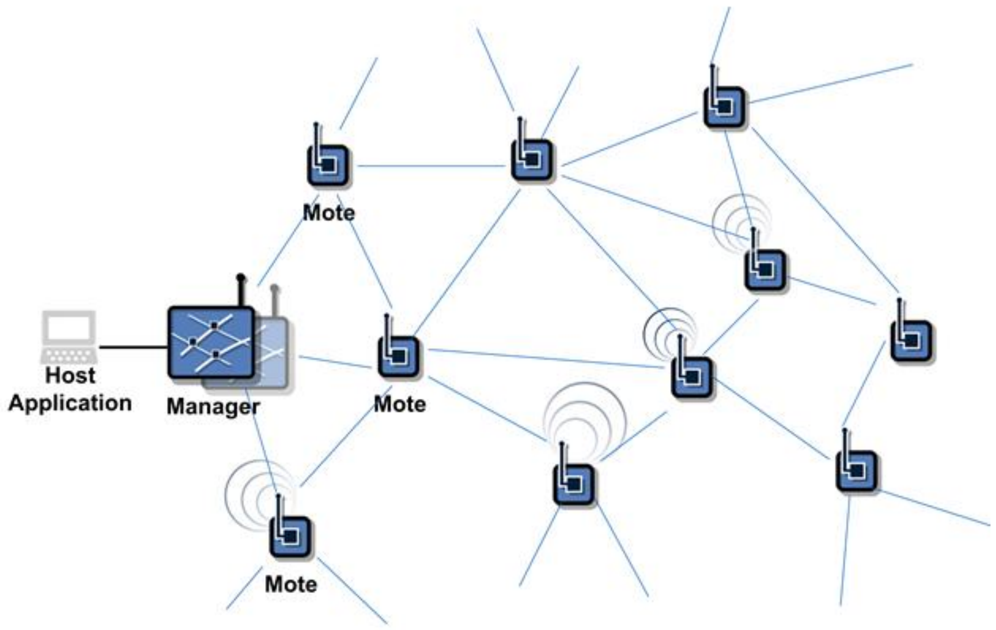
USNs have applications across many industry sectors and conceptually have availability beyond geography to be described as the 'anywhere, anytime, by anyone and anything', and are considered an emerging smart technology.[6].

At the sensor networking layer, wireless ad hoc sensor network solutions are providing self-organising distributed networks formed by autonomous nodes or smart sensors that communicate without the use of additional backbone infrastructure. Smart ad hoc networks are capable of analysing the radio propagation environment, routing paths and traffic volumes in their operation to optimise performance. This allows the network nodes to assess the routing path trade-offs between energy efficiency and the communication of time-sensitive information. Where power availability is limited, the nodes may spend longer periods in a low-power sleep state and thus have slower reaction times for event dissemination. Wireless ad hoc networks are robust and self-healing due to multiple node connectivity and routing paths. If one node fails then the information can be disseminated via an alternative route in the network.

[6] Dr. T. Kelly, Strategy and Policy Unit International Telecommunications Union (ITU), *The 4A Vision: Anytime, anywhere by anyone and anything*, ITAHK Luncheon 8 December 2005, www.cahk.hk/Event/30/images/Luncheon_Dec2005_Powerpoint.pdf, retrieved 14 June 2011.

Smart sensor developments are simplifying sensor networks by implementing 'plug and play' operation specified by industry standard IEEE 1451.[7] Smart sensor modules have onboard analysis capabilities, integrated transducers and applications in a networked environment. For example, a simple temperature sensor requires a controller to convert a raw signal to temperature information and a communications device to interface with a network; whereas a smart sensor will convert the raw data signal to a temperature unit of degrees Celsius and automatically establish a network connection to pass on the information.[8] Smart sensors also have the ability to intelligently interact with the environment.[9] For example, some smart sensors act as nodes or motes to exchange communication with neighbouring nodes, in order to form self-healing ad-hoc networks that provide improved reliable delivery of information (see Figure 2).[10]

Figure 2 Smart wireless sensor network



Wireless-based technologies such as Wifi, ZigBee and 6LoWPAN are playing an increasing role at the sensor layer. Wifi has gained wide acceptance in networks where power sourcing is not a major issue. ZigBee provides a suite of non-IP protocols, which are an implementation of the IEEE 802.15.4 standard for wireless personal area networks (WPAN) to provide communications with better speed response and lower power characteristics. The 6LoWPAN standard uses IPv6-based addressing over a low-power WPAN with limited power requirements. It is suited to wireless sensors applications where low power consumption and direct device addressing are desirable.

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[7] IEEE Standards Association, *1451.4-2004 – IEEE Standard for A Smart Transducer Interface for Sensors and Actuators – Mixed-Mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats,* http://standards.ieee.org/findstds/standard/1451.4-2004.html, retrieved 14 June 2011.

[8] Smart Sensor Systems, *What are Smart Sensor Systems?* www.smartsensorsystems.com/What_are_Smart_Sensor_Systems.htm, retrieved 25 March 2011.

[9] D. Menon and N. Soori, AISSMS's Women's College of Engineering, *Smart Sensors*, www.scribd.com/doc/23709008/Smart-Sensors, retrieved 25 March 2011

[10] Dust Networks, *Technology Overview*, www.dustnetworks.com/technology, retrieved 25 March 2011.

Data mining and analysis

The underlying strategic value of sensing and monitoring is in the information derived from the data acquisition, mining and the analysis processes.

Over recent years, data processing has been simplified and streamlined through the use of data centres and high-speed cloud computing capabilities. Data analysis is now automated to the extent that pattern recognition processes are executed in near real-time.[11] Intelligent applications can sense events, send data to a remote centre for analysis and receive a response in the form of information to assist in a decision or initiate an action. Stream computing technology is emerging to provide real-time fast analysis of massive volumes of data to help with timely decision-making, before data is saved to databases.[12] Multiple continuous streams of data may originate from sensors, cameras, news feeds and a variety of other sources to be classified, filtered, correlated and transformed into informed decisions.

Companies are developing systems and strategies to convert momentary data into linkable information. IBM's Smarter Planet Program focuses on a new generation of smart products comprising services, devices and software to form an intelligent ecosystem or 'system of systems' architecture.[13] Hewlett Packard has also developed their CeNSE technology—Central Nervous System for the Earth. The high-performance sensing technology consists of a trillion nanoscale sensors and actuators embedded in the global environment and connected via an array of networks with computing systems, software and services to exchange their collective intelligence among analysis engines, storage systems and end-users.[14]

The internet of things

More data originates from the operation of deployed sensors that have minimal human intervention than from user interfaces to equipment and peripheral devices such as keyboards. Using the communications infrastructure of the internet, widely distributed sensors and actuators form an electronic ecosystem known as the 'internet of things'. Emerging areas of activities for the internet of things can be cast into two broad categories:

> data information and analysis

> automation and control.[15]

As technology and networks link more things, increasing volumes of information and improved data analysis is available for decision-making. For example, embedded mobile devices can track location information and usage behaviours to provide information that allows for more cost-effective management of assets. Data monitoring of environments and infrastructure can also result in information to enhance situational awareness of weather, traffic and buildings. Long-range analytics can also be applied to historical sensor data to assist in planning, marketing and investment. In retail, historical data may be used to profile purchase choices and directly market similar

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[11] www.google.com/mobile/goggles/#text

[12] R. Rea, IBM Software Group, IBM InfoSphere Streams, *Redefining Real Time Analytic Processing White Paper*, http://public.dhe.ibm.com/software/data/sw-library/ii/whitepaper/InfoSphereStreamsWhitePaper.pdf, retrieved 14 June 2011.

[13] IBM, *A Smarter planet starts with smarter products*, www-01.ibm.com/software/rational/announce/smartproducts/, retrieved 14 June 2011.

[14] J. Wacker, The Next Big Thing, The HP Blog Hub INNOVATION, *Hundreds of Thousands of Sensors Make CeNSE for Shell*, http://h30507.www3.hp.com/t5/The-Next-Big-Thing/Hundreds-of-Thousands-of-Sensors-Make-CeNSE-for-Shell/ba-p/80214, 15 February 2010, retrieved 14 June 2011.

[15] M Chui, M. Loffler and R. Roberts, '*The Internet of Things*', *McKinsey Quarterly*, March 2010, www.mckinseyquarterly.com/The_Internet_of_Things_2538, retrieved 14 June 2011.

products. In health care, long-term continuous monitoring may provide better diagnosis and subsequent treatment not otherwise identified.

The automation and control category generally uses sensor data derived from a particular process and subsequent analysis in feedback loops to modify and improve that process. This can be as simple as water irrigation in response to soil moisture sensors. The key objective is process optimisation, whether it is for quality, time and waste reduction, energy efficiency or human intervention. More complex autonomous systems involve real-time sensing of unpredictable conditions and require instantaneous autonomous responses.

Machine-to-machine communications (M2M)

In a way, M2M is a subset of the sensing and monitoring ecosystem as it excludes devices that are monitored and controlled directly by people. Central servers and multiple devices that do not require direct human interaction fall into the M2M definition. There are forecasts of M2M device numbers in orders of magnitude greater than that of today's personal devices, which already exceed 5.0 billion.[16] While there are approximately 75 million cellular M2M connections in the world, this is expected to increase to 225 million by 2014.[17] Some bullish forecasts are in the tens of billions of connected devices by 2020.[18]

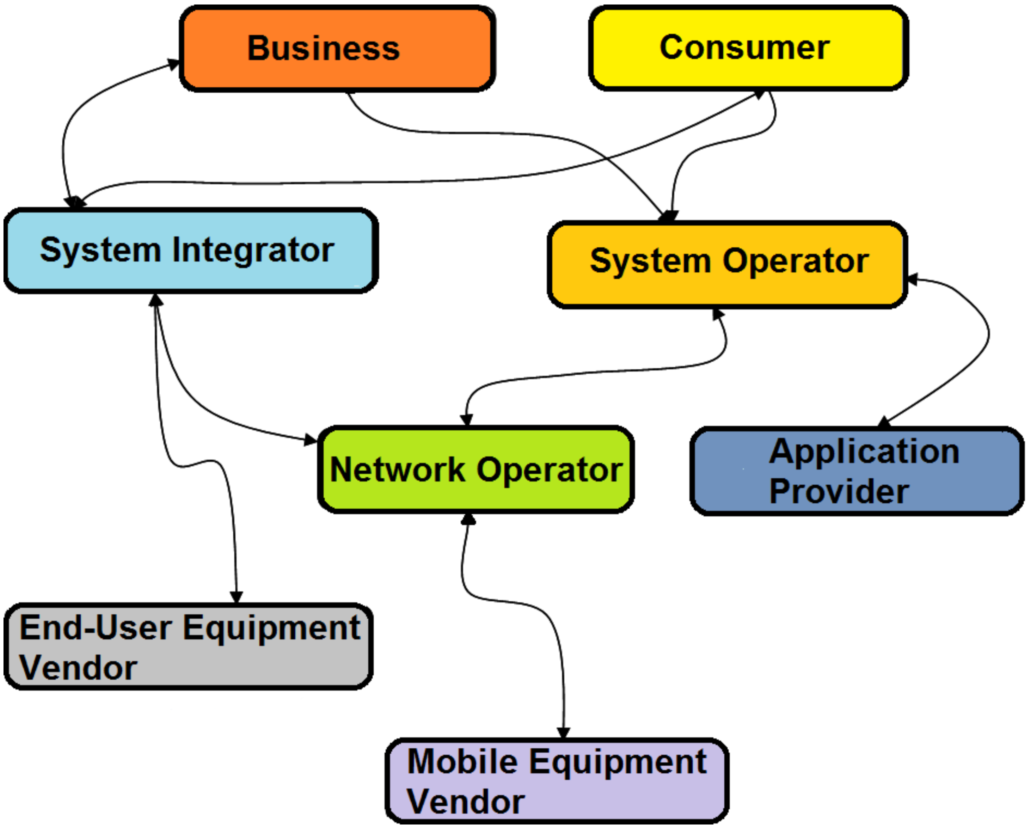
The M2M value chain is a complex one in which variable end-to-end solutions may involve multiple vendors and operators. The chain includes sensors to make measurements, embedded modules or devices to transmit the data, communications networks to carry data, and middleware platforms and application software to convert data into useful information. Figure 3 shows a number of entities involved in the delivery of a customised service between business and customer.

[16] International Telecommunications Union, Newsroom Press Release, *ITU sees 5 billion mobile subscriptions globally in 2010 – Strong global mobile cellular growth predicted across all regions and all major markets*, 15 February 2010, www.itu.int/net/pressoffice/press_releases/2010/06.aspx, retrieved 14 June 2011.

[17] Northstream Strategy and Sourcing, Whitepaper, *The revenue opportunity for mobile connected devices in saturated markets*, February 2010, http://northstream.se/wp-content/uploads/2010/02/The-revenue-opportunity-for-mobile-connected-devices-in-saturated-markets.pdf, retrieved 14 June 2011.

[18] 'Ericsson advises Aussie telcos on M2M strategies', *Exchange Daily*, No. 410, 14 October 2010.

Figure 3 The M2M value chain



Specialist middleware platform providers have recently emerged to enable the important linkage between the network and processes that provide the end-user with real-time visibility and control. Middleware platforms provide a set of services that basically remove the need to manage and understand the underlying enabling technology. Middleware providers are partnering with mobile network operators (MNOs) to pursue M2M opportunities. In Australia, Telstra has teamed up with platform provider Jasper Wireless to offer Telstra's Wireless M2M Control Centre on its Next G network.[19] Globally, interdependence among middleware market players is high, as it provides quick entry into what is a fragmented and complex market.

While initial offerings of M2M are leveraging existing mobile technology based on personal devices, this will not be sustainable for the forecast number of devices. The current removable SIM chips, dynamic IPv4-based addressing and small data volumes are expected to give way to embedded SIMs, fixed-IPv6 addressing and streamlined virtual private networks (VPNs) for larger secure volumes of data. Moves by the cellular industry to standardise embedded SIMs are occurring within the global GSM Association (GSMA). GSMA is set to launch a streamlined process for new categories of mobile devices. SIM vendors and MNOs are working with standardisation bodies ETSI and 3GPP to finalise the specifications for a new physical form factor for embedded and integrated SIM devices.

[19] Telstra, Media Centre Announcements, *Telstra launches wireless machine-to-machine service offering to connect business and consumer devices*, 28 September 2010, www.telstra.com.au/abouttelstra/media-centre/announcements/telstra-launches-wireless-machine-to-machine-service-offering-to-conne.xml, retrieved 14 June 2011.

Today's monitored world

Many aspects of daily life and information used for decision-making are already derived from data collected in various sectors of the digital economy. Everyday considerations like food, health, power production and consumption, the physical environment and human interactions are monitored using information collected, stored and analysed through digital communications technologies. This section examines sensing and monitoring developments in use across various industry sectors in Australia.

Food

The food industry has widely adopted sensing and monitoring technologies in its production, processing, distribution and sales processes.

Sensor networks play an important role in minimising the risk of hazardous or poor quality food products being sold for human consumption. Sensors can be used to track, trace, and monitor products by employing transducers that measure immediate environmental aspects—such as light, heat, moisture, location and time—that are important to the quality management of perishable products. Australian viticulture is using sensing and monitoring in the growth of grapes to measure wind speed, temperature, light, humidity and soil moisture, in order to conduct analysis that helps optimise plant growth and prevent crop loss through climatic factors such as excessive heat, light or frost[20] [21]. Sensors play a role in the fermentation and production process where they are used to measure and monitor gases, acids and tannins that affect the final product. Sensors are also deployed to monitor the environmental conditions of the storage and distribution facilities such as cellars and freight vehicles.

Live produce may also be monitored, from the primary producer to the dinner table. Australia uses the National Livestock Identification System (NLIS) to identify and trace livestock such as cattle, sheep and goats.[22] NLIS allows individual animals to be identified and tracked from the property of birth to slaughter for bio-security, meat safety and market access. Livestock traceability improves overall product integrity by assisting in disease management and continuous animal monitoring through feed and weight sensing. The system relies on radiofrequency identification (RFID) tags that are attached to the animal's ear or inserted under the skin. Sensors are used to identify livestock when moved from location to location and to update information about individual animals on a centralised NLIS database. Figure 4 illustrates the application of sensor networks in livestock management.

[20] Pridham Viticulture, Vineyard and Land Management website, www.pridhamviticulture.com.au/services.htm, retrieved 14 June 2011.

[21] Sentek technologies, www.sentek.com.au/products/products.asp, retrieved 14 June 2011.

[22] Meat & Livestock Australia, *Meat Safety and Traceability—Livestock identification*, www.mla.com.au/Meat-safety-and-traceability/Livestock-identification, retrieved 10 February 2011.

Figure 4 NLIS wireless sensor network application

Source: Meat & Livestock Australia

Applying sensor network technology to manage and monitor the movement of perishable products from producer to reseller is significant in minimising loss, maximising quality and complying with certain legal obligations. Ceebron Pty Ltd developed the *Smart Trace* system, partnering with Meat & Livestock Australia, Motorola Inc. and Minorplanet Asia Pacific.[23] This uses RFID smart sensor tag technology to monitor perishable food products throughout the supply cold chain at pallet-load level. The sender registers, activates and attaches a non-returnable tag to the pallet, which is loaded into the transport vehicle with other tagged pallets. This establishes a local wireless ad hoc network to send continuous dynamic data to the onboard gateway, which then forwards the data with GPS information via a cellular network to a monitoring server. The server analyses the data and compiles relevant information into customised reports. Both the sender and recipient of the goods can receive information collected from the *Smart Trace* system to meet regulatory compliance obligations, and collect information about a product's environmental conditions and the length of time it was in transit. The collected information can provide a good indication of overall quality and potential shelf life of the product.

At the point-of-sale (POS), individual product items are identified or sensed by barcode and RFID systems. Barcodes require line-of-sight scanning while RFID has the advantage of being proximity-sensed and may also include smart tags to store extra data. For example, incoming and outgoing stock on pallets can be scanned without having to pull apart the pallet to sight and scan the tag. RFID tags can provide value-adding information such as the amount of incoming and outgoing stock, shelf life duration, environmental conditions and current stock levels in a warehouse. Warehouse sensors can be used to more efficiently manage inventory stock through automated stocktaking and reordering processes that lead to overall stock reduction.

[23] Ceebron, *Smart Trace Online Monitor*, Company Mission, www.smart-trace.com/mission.php, retrieved 14 February 2011.

RFID tags use radio signals to wirelessly transfer additional information about the product such as movement and storage history. The fact that RFID technology can be proximity-sensed and pass on additional information beyond the product identification makes it attractive for self-service POS outlets. At the POS, RFID can even replace the cashier with an automated system that needs no barcode scanning.[24] The POS system may also conduct a contactless credit card transaction with the approval of the customer by using wireless near-field communications technology to pay for the items at checkout. This can improve customer experience by reducing overall time at the POS.

Sensing and monitoring is an integral part of the food sector that contributes to a more efficient supply chain. It improves traceability and the management of bio-risks, provides a basis for meeting compliance obligations, and gives consumers and industry a wider range of information about the product quality.[25]

Health

The growing e-health industry uses sensing and monitoring technologies for pharmaceutical handling and remote patient diagnostics. Accurate and readily available information regardless of the remoteness of parties is now possible and using sensors and communications networks is extending the reach of health services.

Pharmaceuticals

Pharmaceuticals can lose their effectiveness if not stored or handled appropriately. Regulatory compliance obligations administered by the Australian Government's Department of Health and Ageing Therapeutic Goods Administration have prompted the pharmaceutical industry to adopt sensor networks to better monitor the storage and handling of pharmaceuticals.[26]

The pharmaceuticals distribution chain is using RFID to allow traceability and monitor storage and transport conditions throughout the supply chain from manufacturer, distribution centre, retail supply and hospitals. Hospitals can use sensor technology to identify and monitor patient medications. RFID can associate pharmaceutical history with particular patients to ensure prescribed qualities and processes are met. It also enables asset tracking of trolleys and medical equipment, leading to better management of pharmaceuticals and reducing the risks associated with mishandling the transport of medications.[27]

Health monitoring

Heath monitoring uses sensors to monitor patient conditions both locally and remotely. It provides improved patient care through early detection of adverse health conditions and can influence patients' behaviour to improve their ongoing health.[28] Bio-sensors provide point-of-care monitoring for a broad range of patient conditions. These may include measuring specific components such as heart rate, blood pressure and body

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[24] J. Haefner, *Top 5 Future POS Software Technologies*, Point of Sale Software Buyers Guide, www.possoftwareguide.com/articles/future-pos-software.html, retrieved 15 February 2011.

[25] Software Advice Inc., *An RFID Primer for the Small Retailer*, www.softwareadvice.com/articles/retail/an-rfid-primer-for-the-small-retailer/, retrieved 15 February 2011.

[26] National Coordinating Committee on Therapeutic Goods, *Australian Code of Good Wholesaling Practice for Medicines*, 1 April 2011, www.tga.gov.au/pdf/manuf-medicines-cgwp-schedule2-3-4-8.pdf, retrieved 15 February 2011.

[27] Avery Dennison, *How RFID Can Add Value in Healthcare and Pharmaceutical Tracking and Tracing*, Real-World RFID, www.rfid.averydennison.com/online-press-kit/white-papers/RFID-Healthcare-Pharma.pdf, retrieved 2 March 2011.

[28] G. Virone et al., *An Advanced Wireless Sensor Network for Health Monitoring*, Department of Computer Science, University of Virginia, www.cs.virginia.edu/papers/d2h206-health.pdf, retrieved 5 October 2010.

temperature, and diagnosing or monitoring certain medical conditions. Patient medical data collected from bio-sensors can be forwarded to medical facilities or specialists for analysis.

Hunter Nursing, a NSW regional nursing agency, is collaborating with Intel in a telemedicine trial and remotely monitoring 50 elderly patients by using the Intel Health Solution device, via fixed and mobile broadband connections.[29] Each patient was issued with the Intel Health Guide, an intuitive remote device employing a 10-inch touch screen with a camera (see Figure 5). The patients use the Intel Health Guide to measure blood pressure and weight. They are also able to engage with their clinicians via video conference to undertake video observations and discussions. So far, the trial has shown positive signs—fewer hospitalisations, and efficient use of nursing and clinical staff resources through online interaction rather than patient visits. Patients have also attained a greater understanding of their own health management. The availability and use of a broadband communications service was an integral part of the e-health solution servicing regional and remote areas.[30]

Figure 5 Intel Health Guide

Smartphones in healthcare

The wide availability of smartphones and developments in bio-technology sensors have led to a range of new smartphone-based medical tools. For example, an ultrasound probe with USB interface can connect to a smartphone or laptop computer to greatly improve access to medical technology through lower costs and portability.

[29] J. Gliddon, 'Hunter Nursing embraces telemedicine', *eHealth Space*, 30 June 2010, http://ehealthspace.org/casestudy/hunter-nursing-embraces-telemedicine, retrieved 21 February 2011.

[30] J. Gliddon, 'Hunter Nursing drives health care off the road', *eHealth Space*, 5 August 2010, http://ehealthspace.org/casestudy/hunter-nursing-drives-health-care-road, retrieved 19 April 2011.

Smartphones provide a convenient platform for mobile healthcare applications as they not only have sensing and diagnostic capabilities but are able to connect medical services to patients through mobile communications networks. The smartphone's combination of powerful processing and connectivity can offer low-cost access to health services from an increasing range of healthcare applications. According to research2guidance, 500 million people will be using healthcare mobile applications in 2015. Currently, there are 17,000 mobile health applications in major application stores.[31]

Researchers at Edith Cowan University and clinicians from the Mercy Hospital, Mount Lawley are working to improve prenatal care in isolated communities by designing a portable foetal monitor for expectant mothers to use. When the foetal monitor is connected to a smartphone, the expectant mother can check for signs of foetal distress and relay vital information to healthcare professionals.[32]

The development of small peripheral blood-analysis devices designed to connect to smartphones would help diagnose patients with conditions such as cardiovascular disease. According to Network World, patients could pick up the equipment from a medical outlet and run the test themselves without needing to visit the doctor or have the test conducted at a medical office.[33]

Attachable microscope lenses designed for smartphones will allow medical professionals to access and analyse captured images transmitted from a smartphone. The microscope can be used to diagnose conditions such as skin diseases, ear aches and sore throats. According to Cellscope, their smartphone-attachable low-cost microscopes allow users in developing countries to capture images from patients and send them to trained professionals for analysis.[34]

Developments in bio-monitoring technology, smartphone sensors and application platforms are providing increased availability and more frequent access to medical services in remote areas via mobile communications networks. These sensing and monitoring applications function as virtual medical instruments to assist in the early detection of illness. This should result in a lower cost to both the health services industry and consumers. Smartphones are a convenient monitoring platform complete with a personal communications gateway and, along with sensors, will continue to be developed as virtual medical instruments.

Medical sensors technology

Developments in nanotechnology will extend miniaturisation of sensors to a component scale between 0.1 and 100 nanometers. Nanotechnology will be dependent on the development of assemblers that enable the formation of molecular bonds, to ultimately enable the manufacture of nanoscale products. These developments will be a key to biomedical wet sensing, where smart miniaturised devices will be able to provide instant medical diagnosis when in contact with a drop of

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[31] research2guidance, *500m people will be using healthcare mobile applications in 2015*, 10 November 2010, www.research2guidance.com/500m-people-will-be-using-healthcare-mobile-applications-in-2015/, retrieved 18 February 2011/

[32] Dr A. Tan and Dr M. Masek, *Fetal Heart Rate and Activity Monitoring via Microsoft Smart Phones*, Edith Cowan University, http://research.microsoft.com/en-us/events/mhealth2009/tan-masek-presentation.pdf, retrieved 16 February 2011.

[33] T. Greene, 'IPhones and Droids could speed medical tests, cut costs', *Network World*, 11 January 2011, www.networkworld.com/news/2011/011111-iphones-droids-medical-tests.html, retrieved 16 February 2011.

[34] CellScope mobile medical microscopy, http://cellscope.berkeley.edu/, retrieved 18 February 2011.

blood.[35] While nanotechnology, or molecular manufacturing as it is sometimes referred to, holds promise it is still an area yet to reach its full potential.

Device self-sufficiency through energy harvesting is also emerging as an important factor in support of the miniaturisation and proliferation of sensors. Power-harvesting technology and improved energy management techniques liberate sensors from bulky power source connections and batteries, allowing them to be used in a wider range of autonomous applications. Sensors can harvest energy by using a range of harvesting technologies to support data sensing and transport operations. Energy can be harvested from light, radio frequency (RF), vibration and thermal sources. In 2009, IMEC won the 2009 Frost and Sullivan Award for Technology Innovation for integrating an electrocardiography (ECG) system, employing both solar cells and thermoelectric generator (TEG) modules, onto a shirt.

Disposable low-cost sensor technology is emerging due to miniaturisation, embedding and power harvesting. Digital Plaster allows carers to monitor particular characteristics of patients such as heartbeat, temperature and respiration. The plaster also allows patients to be monitored at home rather than occupying a bed for longer at a hospital.[36]

Power

Sensing and monitoring is playing an increasingly important role in the power industry and for all consumers. Sensors are a key component in smart electricity grids and smart home technologies that permit electricity producers and consumers to efficiently manage power resources through information gained from production, distribution and use of power.

While sensing and monitoring is already widely used in the power industry, it is relatively new for consumers to have smart appliances and smart meters. At the Google I/O presentation in 2010, Google announced the release of its Power Meter application to enable households to monitor their energy consumption. Google Power Meter gives users access to information similar to that available to suppliers—it is a web-based application that allows individuals and organisations to use network sensor devices to collect and present information about household and appliance energy consumption. It presents the energy use graphically and provides some analytical tools to help the user better manage their energy use.[37]

The Google Power Meter API allows Google-partnered utilities, application developers and meter manufacturers to integrate the application within their respective products and services. Figure 6 illustrates the aggregated data uploaded to the Google Power Meter user application.[38] In Australia, SmartNow supplies a monitoring product comprising a Current Cost device that is partnered with the Google Power Meter middleware.[39] Current Cost is a global supplier of energy monitoring products.

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[35] Analog Devices Inc., *Impedance Measurement Blood Analysis Systems*, www.analog.com/en/rfif-components/direct-digital-synthesis-dds/products/technical-articles/Blood_Analysis_Systems_Require_Wide_Bandwidths/resources/fca.html, retrieved 14 June 2011.

[36] Toumaz, *Toumaz Invited to speak at the World of Health IT 2007*, October 2007, www.toumaz.com/news.php?id=39, viewed 22 March 2011.

[37] Google.Org project, *What is Google PowerMeter?*, 2011, www.google.com/powermeter/about/about.html, retrieved 23 February 2011.

[38] The Official Google Blog, *Energized about our first Google Power Meter partners*, 19 May 2009, http://googleblog.blogspot.com/2009/05/energized-about-our-first-google.html, viewed 1 March 2011.

[39] SmartNow, *Google PowerMeter Australia – tracking your standby power use*, 4 August 2010, www.smartnow.com.au/?p=7, retrieved 14 June 2011.

Figure 6 Google Power Meter daily power consumption trace

Connected Environments Pty Ltd established a global online database and data brokerage platform allowing developers to upload sensor data. The cloud-based product, known as Pachube, allows millions of IP-based sensors to upload data to a hosted platform for developers of services and applications.[40] Pachube is providing a common accessible format for data feeds and sensors similar to what YouTube has done for video-sharing.

Smart metering enables a higher level of interaction between users, utilities and energy retailers. Smart meters are essentially bi-directional connected sensor devices that are used in smart grids to not only provide consumption data but also control smart appliances. Smart grid technology provides a flow of information that enables the control and monitoring of smart appliances. Smart grids, smart meters and supporting networks monitor and manage the power supply and consumption in real-time.

The ITU-T G.hn working group on home networking has released specifications for smart grid products allowing multiple manufacturers to develop products that deliver low-power consumption at low cost, increased performance, better reliability, and improved security for smart grid and other lower bit-rate applications.[41] Smart grid products include smart meter in-home displays and smart thermostats; plug-in electrical vehicles and electrical vehicle charging equipment; and smart appliances such as washing machines, dryers, dishwashers, and heating, ventilating and air-conditioning systems. It is intended to allow end-users to better manage their energy consumption, and utility providers to better manage their energy resources.

Our environment

Whether indoors, outdoors or in transit, it is increasingly likely that one's immediate surroundings are being sensed and monitored to provide information about

[40] Pachube, data infrastructure for the Internet of Things, www.pachube.com, retrieved 14 June 2011.

[41] International Telecommunications Union, 'ITU-T Home Networking Standard given Smart Grid specs', *ITU-T Newslog*, 20 January 2010, www.itu.int/ITU-T/newslog/Home+Networking+Standard+Given+Smart+Grid+Specs.aspx, retrieved 3 February 2010.

environmental conditions and individual location. This is also possibly providing linkages to augmented information. A combination of fixed localised sensors and mobile smartphone sensors can provide observational context from both personal and local perspectives.

Indoors

Indoor environments can be monitored for many purposes including security, crowd movement and, more commonly, heating, ventilation and air-conditioning (HVAC). HVAC systems use sensing and monitoring technologies to gather data on indoor conditions to manage temperature, humidity, air pressure, air quality and plant equipment. Collected data is fed back to a system controller to maintain optimum indoor environmental conditions and reduce energy consumption.

Sensor technology plays an important role in the management of the heat generated by equipment in data centres, which can be up to 50 per cent of the centre's overall energy consumption. Embedded sensors in both IT equipment and HVAC systems provide data to establish the optimum balance between server loads and cooling systems.

In transit

Transportation systems, particularly road transport that uses road integrity, traffic management and signalling systems, all involve sensing and monitoring. Data is collected from a wide variety of sensors and sources that are both fixed and mobile.

Google Maps offers free live traffic updates by collecting anonymous data from smartphones often referred to as 'crowdsensing'—where individuals with sensing and computing devices collectively share information to measure and map events of common interest. Using mobile network data, and GPS sensor location and time data, information is mapped to form a picture of traffic conditions.[42] Participants enable Google to access GPS-based location data from their smartphones, which are aggregated and analysed to create map overlays in Google Maps. The overlays are coloured-coded levels of congestion superimposed over roads, to show categories of traffic conditions. According to Google, individual and device privacy is maintained in the crowdsensing process by deletion of raw data after it is processed into information. Google Traffic can assist people in preplanning trips, avoiding congested roads and selecting optimum times to travel.[43]

Vehicle telematics is the integrated use of telecommunications and sensors in vehicles to provide shared information such as driving conditions and estimated time of arrival to drivers, traffic control operators and emergency services. Telematic systems typically use data derived from GPS, anti-collision radar, emergency warning systems, and sources reporting on traffic and road conditions.[44] A range of information leads to better vehicle efficiency, reduces accidental risks and provides an improved commuter and driving experience. The IEEE 802.11p Wi-Fi standard has been developed to support intelligent transportation system applications with ad hoc wireless access in

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[42] Sydney Morning Herald, *Google Maps offers live traffic updates for Australia*, 15 September 2009, www.smh.com.au/digital-life/digital-life-news/google-maps-offers-live-traffic-updates-for-australia-20090915-foro.html/, retrieved 3 March 2011.

[43] A. Foster, 'Get there faster with traffic information on Google Maps', *The Official Google Blog*, 15 September 2009, http://google-au.blogspot.com/2009/09/get-there-faster-with-traffic.html, retrieved 3 March 2011.

[44] The Motor Report, *Daimler and BMW Team up to extend application of Anti-Collision Radar*, 29 May 2009, www.themotorreport.com.au/32760/daimler-and-bmw-team-up-to-extend-application-of-anti-collision-radar, retrieved 4 March 2010.

environments that require short duration communication exchanges between vehicles and roadside infrastructure.

Sensing and monitoring transport infrastructure such as road surfaces, bridges and pathways can give road authorities and developers vital information to manage risks, maintain roads and improve design. The Australian Road Research Board (ARRB) provides sensing and monitoring tools to assess roadways, paths and other forms of traffic-bearing structures to maintain their integrity, safety and reliability.[45]

Outdoors

The broad monitoring of external environments provides valuable information that may influence decisions about outdoor work and recreational activities. This information is provided through the sensing and monitoring of a variety of parameters such as weather conditions, air pollution levels, water quality and noise levels.

Meteorology is one of the oldest sciences to use sensor technologies to observe, record and forecast weather. It relies on a range of sensor technologies to measure conditions such as temperature, humidity, pressure, solar radiation and wind speed. The Bureau of Meteorology provides a service to government, business and individuals detailing weather information and warnings on floods, frosts, fires and cyclones. Historical data from sensor devices also aids government and private organisations to improve structural engineering and facilities planning.

The various environment protection authorities collect data by employing continuous sensing and monitoring as well as from third parties involved in air and water quality and pollutants measurements.[46] [47]

The City of Melbourne local council is using technology experts from the University of Melbourne to draw up plans for a wireless sensor network that will measure sound across the central business district. Data collected from the sensors will help to create a noise map of the city and can be used to manage noisy areas. Barking dogs, loud music, busking, air-conditioners, industrial machines and trucks are some of the noise issues the council is examining. The Melbourne project was reported to be one of the first in the world to monitor and map city sounds over such a large area. The sensor network can also be adapted in future to monitor other parameters such as air quality and weather conditions with results easily distributed over the internet. As part of its planning process, the council already uses sensors to monitor the amount of pedestrian traffic at busy locations.[48]

Outdoor digital cameras have been widely adopted for a variety of monitoring processes, including for recreational activities, traffic management, and environmental and security applications. As a sensor, cameras are able to remotely capture a large amount of visual data that can be analysed to provide wide-ranging information about livestock or vehicle movement, water management and security status.[49]

Disaster management

Sensor networks are also relied on for disaster management and various environmental management schemes that help governments to reduce the risk of

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[45] ARRB, www.arrb.com.au/Home.aspx, retrieved 4 March 2010.

[46] EPA Victoria, *Air Monitoring*, www.epa.vic.gov.au/air/monitoring/default.asp, retrieved 14 June 2011.

[47] EPA Victoria, *Monitoring Victoria's waters*, www.epa.vic.gov.au/water/environment/default.asp, retrieved 14 June 2011.

[48] J. Dowling, 'Shut up, Big Brother is listening', *The Age*, 13 November 2010, www.theage.com.au/victoria/shut-up-big-brother-is-listening-20101112-17r8r.html, retrieved 8 March 2011.

[49] rmTek Remote Monitoring, *About RMTEK*, http://rmtek.com.au/about-2.cfm, retrieved 14 June 2011.

property loss and injury to citizens. Data collected from sensor networks provide valuable information to forecast and predict environmental impacts caused by storms, cyclones, earthquakes, tsunamis and activities that can place building structures or peoples' lives at risk.

The European Earth observation program, the Global Monitoring for Environment and Security (GMES), assists in the development of environmental policies and legislation with a particular focus on climate change. Through a program of ongoing research and development projects on sensor networks, it supports critical decision processes in response to emergencies and humanitarian crises.[50] Some projects under the GMES are based on addressing technological challenges and barriers to improve monitoring and efficient information-handling of real-time crisis management. For example, one objective of the Sensors Anywhere (SANY) project is the acceptance of a future standard applicable to global monitoring for disaster environments.[51]

The National Oceanic and Atmospheric Administration (NOAA) is a US government organisation with a goal to enrich life through science.[52] NOAA uses information derived from sensor networks to measure and monitor weather, marine environments and space weather to provide information services to citizens, emergency organisations and other interested parties. For example, NOAA's satellites provide data from space to monitor coastal waters, relay life-saving emergency beacon signals, and track tropical storms and hurricanes. One of NOAA's users is the Bureau of Meteorology, which collects and uses data from NOAA's satellites to provide similar services to Australian citizens.[53]

Remote sensing

Remote sensing is applied to objects that cannot be physically measured. There are two remote sensing techniques—active and passive. Active sensing techniques employ energy emission systems such as radar, sonar and X-ray to scan and detect objects. Passive sensing detects naturally reflected radiation from objects or areas of interest; for example, human eyes and ears are passive remote sensors that provide data for the brain to gauge distance and direction by receiving light and sound respectively.[54]

In the field of geodesy, the geologic science of the size and shape of the earth, remote sensing deals with the collection of satellite data from various sources including GPS, and forms of radiating or reflected emissions such as magnetic fields, infrared, visible light and ultraviolet radiation. The data collected and analysed provides useful information for a growing range of services. For example, the Geocentric Datum of Australia (GDA) is Australia's latest GPS-compatible datum that is used in many types of maps, and is derived by collecting data from sensor networks and using remote sensing techniques.[55] Australian organisations such as CSIRO, Bureau of Meteorology[56], Geoscience Australia[57] and Landgate[58] use remote sensor networks to:

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[50] GMES, *Overview*, www.gmes.info/pages-principales/overview/, retrieved 9 March 2011.

[51] SANY Sensors Anywhere, *SANY Sensor Anyway – IST FP6 Integrated Project*, www.sany-ip.eu/about_sany, retrieved 9 March 2011.

[52] National Oceanic and Atmospheric Administration (NOAA), United States Department of Commerce, *About NOAA*, www.noaa.gov/about-noaa.html, retrieved 9 March 2011.

[53] Bureau of Meteorology, *NOAA -12, -14, -15, and -16 Browse Service*, www.bom.gov.au/sat/archive_new/browsenoaa.shtml, retrieved 20 April 2011.

[54] RST Introduction, *Technical and Historical Perspectives of Remote Sensing*, http://rst.gsfc.nasa.gov/Intro/Part2_1.html, retrieved 10 March 2010.

[55] International Union of Geodesy and Geophysics, International Association of Geodesy XXII General Assembly, *Geodesy in Australia National Report 1995 – 1999* prepared by the Geodesy Sub-Committee National Committee for Solid Earth Sciences, Australian Academy of Science, July 1999, www.google.com.au/url?sa=t&source=web&cd=1&ved=0CBUQFjAA&url=http%3A%2F%2Fwww.science.or

- observe events
- collect data to provide for services including:
  weather forecasting
  monitoring climate change
  monitoring forests
  conducting surveillance and border security
  fire monitoring
  farm monitoring
  space activity monitoring
- undertaking magnetic field surveys to assist industries such as mining.[59]

Social and recreational

Social and recreational pursuits are increasingly drawing on information derived from geo-locational sensors, performance-based sensors, and sensors that enhance the interactions between humans and machines.

Smartphones

Smartphones continue to develop interactive capabilities using a range of sensors embedded and integrated into the device. ABI Research anticipates that the sensor-driven user interface (UI) will be an emergent theme in the next wave of mobile UI innovation by turning objects, locations and people into networked interactive elements.[60] Proximity sensors, GPS, accelerometers, gyroscopes, digital compasses, light sensors, temperature sensors, improved touch sensors and audio sensors are in the technological mix that developers are using to create innovative smartphone applications.

The use of gyroscopes means that smartphone applications are now spatially aware. This is particularly useful for stabilisation of photographic sensors to improve related digital imaging functions.[61]

Improved smartphone camera technology allows users to use their mobile phone to record in high definition and exploit new imaging applications. For example, the health sector can use high-resolution imaging for skin and eye scans for remote diagnosis.

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g.au%2Fnatcoms%2Fdocuments%2Fgeodesy.pdf&ei=dmyuTaeUMZDOrQfF96iJCg&usg=AFQjCNGDeSptS12TJoCNq32t-brHPFuzrA&sig2=GDdTRfFmvfBd-XDQ4JkeYQ, retrieved 10 March 2011.

[56] Bureau of Meteorology, www.bom.gov.au, retrieved 14 June 2011.

[57] Geoscience Australia, *Earth Observation and Satellite Imagery*, www.ga.gov.au/earth-observation.html, retrieved 14 June 2011.

[58] Landgate, *About Us*, www.landgate.wa.gov.au/corporate.nsf/web/About+Us, retrieved 14 June 2011.

[59] Geoscience Australia, *Magnetic Surveys*, www.australianminesatlas.gov.au/education/down_under/exploration/magsurv.html, viewed 10 March 2011.

[60] ABI research, *GPS Accelerometers and Gyroscopes Will Add Functions to Many Smartphones by 2013*, 30 September 2010, www.abiresearch.com/press/3518-GPS,+Accelerometers+and+Gyroscopes+Will+Add+Functions+to+Many+Smartphones+by+2013, retrieved 15 March 2011.

[61] R. C. Johnson, 'Five Apps That Will Make 2010 the Year of the Gyroscope', *Smarter Technology*, 30 December 2009, www.smartertechnology.com/c/a/Technology-For-Change/Five-Apps-That-Will-Make-2010-the-Year-of-the-Gyroscope/, retrieved 16 March 2011.

Smartphone sensor technology can be used in large-scale participatory distributed sensing applications (crowdsensing). As discussed above, Google collects user data from smartphones to estimate traffic conditions.

Smartphone sensors may also be used in combinations to provide more accurate data. For example, when GPS signals are lost, the resolution of location-based services may be improved by the use of a digital compass, gyrometer and Wifi sensors to provide location details inside buildings.

Sport

Wireless sensor network technology is being used in various sports to collect performance data from athletes, animals and machines. Applied to rowing, this technology is able to collect performance data from both individual team members and the water vessel to analyse rowing techniques and performance through the correlation of high-speed video and accelerometer data.[62] For example, if a team member's technique is causing drag or tilt on the vessel, this can be identified from data analysis.

Similarly, the horse racing industry uses sensors in saddle blankets to assess a horse's physical performance related to training regimes, distance, track condition and other variables.[63]

Achieving millisecond time improvements can make all the difference in motor sports. Sensor technology in motor vehicle racing provides race teams with useful data to monitor, manage, and evaluate the vehicle and driver performance. Formula 1 racing teams are also pushing some of their live data collected by the car sensors with commentary to their websites for fans to see.[64]

Interactive entertainment

The latest game consoles use sensor technologies to track motion, position, elevation, direction, force and light. For example, accelerometers that are embedded in game controllers can measure forces imposed upon it by the gamer. Wii Fit games can measure a user's fitness levels based on forces exerted upon sensors during particular activities.[65]

Nintendo 3DS uses two cameras for stereoscopic image processing and a gyrometer to enhance the user experience through better 3D animations[66] and an array of new games featuring augmented reality.[67] [68] The PlayStation 'move' uses controllers employing a three-axis gyroscope, a three-axis accelerometer, a magnetic field sensor and a colour-changing sphere that is tracked by the PlayStation camera, for more

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[62] J. Llosa et al., 'REMOTE, a Wireless Sensor Network Based System to Monitor Rowing Performance', *Open Access Senors Journal*, 4 September 2009, www.mdpi.com/1424-8220/9/9/7069/pdf, retrieved 16 March 2011.

[63] J.D. Davis, *UC Davis Development of Track-Testing Device for Racehorse Research* video, Wheat Veterinary Orthopedic Research Laboratory, University of California, January 2010, www.youtube.com/watch?v=3Rx3uYiOnJ0, retrieved 16 March 2011.

[64] Sidepodcast, *Live Telemetry and More From F1 Teams This Year*, 10 March 2010, http://sidepodcast.com/post/live-telemetry-and-more-from-f1-teams-this-year, retrieved 16 March 2011.

[65] J. Wagner, 'How Motion Sensor Technology is Revolutionizing Video Games', *Articlesbase*, 5 December 2010, www.articlesbase.com/technology-articles/how-motion-sensor-technology-is-revolutionizing-video-games-3790962.html, retrieved 14 June 2011.

[66] Nintendo 3DS, *3D Without Glasses*, www.nintendo3ds.com.au/#/hardware, retrieved 21 March 2011.

[67] C. Kohler, 'Leaker Reveals "Mystery" Nintendo 3DS Augmented Reality Games', *GAME LIFE*, 22 February 2011, www.wired.com/gamelife/2011/02/nintendo-3ds-ar-games/, retrieved 21 March 2011.

[68] R. Torres, 'Nintendo 3DS Augmented Reality Games Japanese Quick Look', *Game Spot,* www.youtube.com/watch?v=TQhJCgjR1P4, retrieved 21 March 2011.

precise movement detection and tracking. The PlayStation also uses the Playstation eye, which employs camera and sound sensors for augmented reality, command and control.[69]

The Microsoft human interface 'Kinect', promoted for the Xbox 360, replaces user controllers by employing non-contact sensor technology to see, hear and determine distance. The Kinect uses image sensor technology to detect user movements, determine distance and identify objects, as well as audio sensors for sound identification and speech recognition.[70] The Kinect is a human interface device that also has uses beyond game applications. Open source drivers are available to allow developers to create interactive services and applications that are based on movement or gesture. For example, a surveillance system detects crowds by identifying and calculating the number of individuals in an area.[71] The Kinect is being investigated for use in medical procedures as a hands-free tool to control medical imaging equipment, resulting in increased efficiencies and a better focus on medical procedures. Other applications under developments for the Kinect help the visually impaired with navigation.[72]

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[69] PlayStation, 'PlayStation Move motion controller revealed', *PS3 News*, 11 March 2010, http://au.playstation.com/ps3/news/articles/detail/item268480/PlayStation-Move-motion-controller-revealed/, retrieved 21 March 2011.

[70] GEARLIVE, *E3 2009: Project Natal Xbox 360 Announcement*, 2 June 2009, www.youtube.com/watch?v=p2qlHoxPioM, retrieved 21 March 2011.

[71] A. Alahi, 'Connecting Kinects for Group Surveillance', *EPFL News*, 21 December 2010, http://actu.epfl.ch/news/connecting-kinects-for-group-surveillance/, retrieved 14 June 2011.

[72] R. Trenholm, 'Microsoft Kinect scrubs in to help surgeons to operate and the blind see', *cnet uk*, 18 March 2011, http://crave.cnet.co.uk/gamesgear/microsoft-kinect-scrubs-in-to-help-surgeons-operate-and-the-blind-see-50003203/?tag=mncol;txt#ixzz1GyHmeGqr, retrieved 21 March 2011.

Discussion

Regulatory implications

The ACMA is interested in the ways emerging smart technologies affect service delivery to consumers. These include the use of next-generation networks, the convergence of services, and the growth in smart devices and networks, which all affect how regulation can provide the best outcome for all stakeholders. The ACMA views sensing and monitoring technologies as smart technologies that will have a potentially significant impact on how information-based services are developed for use by consumers.

Devices everywhere

The advent of the internet of things introduces a raft of regulatory implications in what is already a challenging technological and operational environment for industry and consumers. The sheer number of devices will require new processes of connection and management. In the future, the majority of communications devices will be associated with a function and service that does not involve a person. Devices will need to be interoperable with a variety of networks and be able to autonomously join and leave networks as required. Trusted relationships between consumers and industry will need to be extended to devices.

Addressing a predicted population of devices in the order of tens of billions will require new technology to deliver reliable, scalable and accessible services. The IPv4 addressing scheme has only 2^{32}—or 4.3 billion—addresses and is nearly exhausted. IPv6 is an addressing scheme being introduced that supports considerably more addresses—2^{128} or 340 trillion groups of one trillion addresses—a number unlikely to be exhausted any time soon. IPv6 addressing will allow devices to be directly mapped and accessed on very large networks such as the internet. Devices can have a unique global identifier or an address range that is unique to a network of sensors.

IPv6 also has an inherent network security capability. The Internet Protocol Security (IPSec) is integrated into the design of the IPv6 architecture and is mandated as a fundamental interoperability requirement. It provides for standardised end-to-end encryption and/or authentication at the network layer, and may be deployed to protect any upper layer application. There are two modes of operation for IPSec—transport mode, where all packet payloads are encrypted while the source and destination addresses are not; and tunnel mode, where the entire packet is encrypted and then encapsulated into a new IP packet for communication. Tunnel mode can be used to create virtual private networks (VPN) that allow for communications to traverse public networks securely. This has implications for legal interception of communications traffic between devices as well as for individuals.

Wireless and cloud environments

Wireless cellular networks will play a significant role in sensing and monitoring for both human-interfacing devices such as smartphones and M2M devices, as they provide not only connectivity but mobility. Embedded mobile sensors and their associated services depend on wireless networks to offload their data to back-end servers in the cloud. The cloud provides unprecedented scalability and resources for the collection and analysis of large-scale sensor data.

Cloud services are likely to play a large role in sensing and monitoring as they provide computing capabilities and storage capacities not yet available on the sensor devices themselves. Utility companies and others that provide critical services need to also consider the reliability of their services. While some services such as email, telephony, data and customer support are now being provided by cloud environments, sensor monitoring for health and critical infrastructure will require robust operational and redundancy capabilities to avoid life-endangering outages.

Emergencies

The 000 and 106 services provide voice and TTY communications to emergency service operators nationwide. The Emergency Call Service (ECS) is based on human interaction to exchange information about emergencies. In an increasingly connected and automated world, sensor devices are being relied on to provide continuous monitoring. Automatic fire alarms systems are widely used in the chain of alert to emergency fire services and automated surveillance systems may also instigate actions to alert police.

The use of M2M communications to facilitate improved responses to emergency situations is an area of interest to the ACMA. While the ACMA has a role to ensure that consumers can access the ECS, there is an increasing interest in enhanced information that can be provided with the call. This includes location-based information that is associated with the originating number, and the capabilities of both the calling device capabilities and the carrying network. This enhanced information is particularly useful in emergency calls where the circumstances of the emergency impair voice communication. Smartphones provide this capability through the use of inbuilt sensors, software and intelligent networks.

These capabilities are moving beyond personal devices, such as phones, to devices embedded in vehicles, buildings and e-health systems. For example, eCall is a pan-European in-vehicle emergency call system that uses the European emergency number 112 in the event of an accident. The onboard eCall device transmits an emergency call to the most appropriate public service answering point (PSAP), along with certain vehicle-related data, notably the vehicle's precise location. The system is based on the use of the single European emergency number 112, which will allow its interoperability throughout the European Union (EU). The emergency call can be triggered either manually by the occupants of the vehicle or automatically in the event of a serious accident, due to sensors installed in the vehicle. The eCall system addresses access issues related to border and language barriers. All new vehicles should eventually be equipped with the eCall system and the European Commission, the EU's executive body, expects implementation by 2014.[73]

Opportunistic networks have been mooted as alternative communications networks for disaster situations where normal networks have failed.[74] Opportunistic networks are based on the mobility characteristics of devices that present an opportunity to connect rather than a request to connect. Networks can be built on nodes that communicate with each other regardless of knowledge about the network topology. Information routing through an opportunistic network is dynamic, while the sender and destination are static.[75] Opportunistic computing uses such networking by considering the opportunistic use of any computing resource available in the network. Smartphones and smart sensors may use opportunistic networking and computing through the use of Wifi or bluetooth to discover networks, establish connectivity and exchange information.

[73] European Commission Information Society, Europe's Information Society Thematic Portal, *i2010 Intelligent Car Initiative - Intelligent Car: eCall*, http://ec.europa.eu/information_society/activities/intelligentcar/technologies/tech_07/index_en.htm, retrieved 14 June 2011.

[74] The Serval Project, *The Serval Project making communications available anywhere, anytime*, 2010, www.servalproject.org/, retrieved 14 June 2011.

[75] M. Conti et al., 'From Opportunistic Networks to Opportunistic Computing', *IEEE Communications Magazine*, September 2010.

Radio spectrum management is likely to play an increasing important role as sensing and monitoring applications grow. Sensors will not only use mobile and fixed wireless networks but connect and convey data via a wide range of frequencies, power levels and data rates, depending on application requirements. This may lead to interference management and coordination issues. For example, sensor networks with a high density of sensors in a small area, such as those using the ZigBee[76] protocol, may be suited to higher frequencies; whereas networks requiring radio penetration of water and steel use the RuBee[77] IEEE1902.1 protocol at lower frequencies. Other applications only require near-field point-to-point communications for tracking and identification such as RFID.[78] The ACMA is the Australian regulatory body for spectrum and, through its five-year spectrum outlook process, monitors technological developments that increase demand for spectrum.[79] Technology also provides the potential for greater spectral efficiency, increased interference mitigation, spectrum re-use and more effective spectrum-sharing in sensor networks across all industry sectors.

Smart junk

The 'internet of things' also marks an era where devices no longer have a human interface, identity and, in some cases, ownership. Identity management of potentially billions of autonomous mobile sensor devices in a global environment presents challenges for sensor network operators, particularly where there are disparate sensor markets and limited standardisation or interoperability of networks, platforms and devices.

A widespread accumulation of lost or rogue devices without traceable identity could interfere with the operation of legitimate sensor networks, effectively creating an interference-prone environment akin to space junk and known as 'smart junk'. Sensor life cycles will also vary depending on the industry sector they are intended for. Removable, disposable, reusable and permanent sensors are all part of the mix in an increasingly monitored world.

Identification of, and responsibility for, such devices is an area of interest for the ACMA, which aims to ensure the community continues to benefit from spectrum assets and is protected from unsolicited communications.

Potential barriers

Sensing and monitoring is only one component segment of emerging smart industries. While it has some historical roots in the enterprise supervisory control and data acquisition (SCaDA) industry, it differs in that it now applies to a global digital economy. Technological advances have created opportunities for innovation, collaboration and growth in smart services. Standards formulation and adoption during this period is a delicate balance in which early standardisation may hamper innovation, but may hold back investment if delayed. The ACMA, through its research and industry monitoring functions, maintains an informed view of these developments to ensure a healthy relationship between consumers and industry that includes elements interoperability, reliability and transparency.

As with all new technologies, there are risks and opportunities. Smart industries inherently open up horizontal communications with other industry elements to reap the

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[76] ZigBee Alliance, www.zigbee.org/, retrieved 14 June 2011.

[77] *RuBee and RFID Differences*, Version 1-6, 1 March 2008, www.rubee.com/White-SEC/RuBee-SellingPoints-190208v1-3.pdf, retrieved 14 June 2011.

[78] GS1 EPCglobal, *Products and Solutions*, www.gs1.org/epcglobal, retrieved 14 June 2011.

[79] ACMA, *Five-year spectrum outlook*, www.acma.gov.au/WEB/STANDARD/pc=PC_312466#fyso, retrieved 14 June 2011.

benefits of information-sharing. This presents an environment with increased cybersecurity risks to sensitive information and infrastructure assets. M2M networks have already been affected by violations that can potentially be disastrous. The Stuxnet worm is malicious software that targets industrial software to subvert programmable logic controllers (PLCs) that interface with sensors and actuators. PLCs are process and automation building blocks found in many industries from manufacturing to power generation.[80]

Certainty in data ownership, security and rights of use are important foundations for a functioning digital economy. Data can be collected from many sources, such as private sensor networks, crowdsensing from smartphones, traffic metrics from network operators, and service and application usage by users.

Ownership of data, data privacy and choice are relevant consumer issues. Consumers are also becoming increasingly aware of invasions to privacy through direct harvesting of information by applications and service providers. In Europe there has been particular concern about the amount of information mined by social networking applications. The concerns revolve around privacy and information ownership, security and longevity of data. Consumers may also be reluctant to adopt technologies that offer little in return for added responsibility and expense. Electricity smartmeters, electronic smartcard ticketing and toll tags are examples of sensing and monitoring applications that have met consumer resistance. Liability for actions of autonomous systems is also a concern when multiple entities are involved in the provision of services to consumers.

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[80] B. Winterford, 'Analysis: Stuxnet dissected', *itnews*, 24 February 2011, www.itnews.com.au/News/249061,analysis-stuxnet-dissected.aspx, retrieved 14 June 2011.

Conclusion

Sensing and monitoring involves the collection of data that ultimately feeds into private and public information systems, which increasingly form the basis of consumer services.

The consumer experience will continue to drive many aspects of sensing and monitoring in providing information to people. The smartphone, as a source of data, has emerged as a device that meets the consumer-centric expectation by providing a rich human interface experience and the ability to acquire and sense information in a personalised environment. The smartphone provides not only the data input and information output but, in some instances, the application platform as well. This can be challenging to providers as functional trade-offs are made between the machine and human interface functionality.

In contrast, M2M devices do not interface with humans and so can be developed to focus on sensor data collection and transport. This means that M2M devices, as a source of data, are not functionally compromised between human and machine-based tasks.

However, sensor applications and environments may vary widely in scale and connectivity, placing added requirements on middleware platforms to aggregate data from multiple sensors, interface with multiple sensor types and support the analysis of growing volumes of diverse data. This has implications for interoperability, network carriage, and the storage and use of this data. The growth of sensed data is also expected to stimulate the global market for vendors that sift data and provide analytics. New software champions will emerge as the Facebooks for sensors as the internet of things dwarfs the internet of people.[81]

A combination of new data sources, existing repositories and the mining of sensor exhaust or unused metadata from previous processes will all contribute to a rich abundance of source data, from which valuable information may be derived.

Sensor data can have many origins and contribute to many information sources. The ownership, control and traceability of both data and derived information have many implications for the privacy of both individuals and organisations. Securing information is becoming increasingly crucial as sensor data becomes increasingly pervasive across a range of sectors within the economy.

The ACMA continues to monitor the developments in sensing and monitoring and welcomes comments on this report.

[81] The Economist, *A special report on smart systems – It's a smart world*, 4 November 2010, www.economist.com/node/17388368, retrieved 14 June 2011.

Glossary

6LoWPAN	Low-power wireless personal area network operating on IPv6. Developed as specification RFC 4944 by the IETF group.
access network	The part of a network that a service provider uses to connect directly to the customer.
actuators	A device that translates information from the digital world into actions in the real world.
active sensing techniques	Employs energy emitters to scan and detect or observe objects of interest. Some active sensing techniques include radar, sonar and X-ray systems.
augmented reality (AR)	Computer-generated imagery that is superimposed onto real-time environments. Advanced AR adds computer vision and object recognition, providing information about the surrounding real world.
ad hoc wireless sensor network	A decentralised wireless network that is not reliant on a continuous pre-existing communications infrastructure.
Application Program Interface (API)	A set of rules and specifications designed for interfacing software applications.
bio-security	Preventative measures to minimise the risk of transmission of infectious diseases.
bluetooth	A wireless communications standard designed for interoperability between wireless devices including headsets, mobile phones and navigators.
data centres	Facility to house computer systems associated with the storage and communications of software and data.
data mining	The process of collecting and aggregating quantities of digital data that may be used to derive information.
e-health	Health care practices supported by electronic and communication processes to monitor, collect and analyse health data, in order to improve doctor-to-patient services. May include electronic health records and telemedicine.
ethernet	The IEEE 802.3 standard used in computer networking technologies for local area networks.
ESP	Everyday Sensing and Perception.
ETSI	European Telecommunications Standardisation Institute.
GDA	Geocentric Datum of Australia.
geodesy	An area of study based on scientific measurements of a planet such as Earth in a three-dimensional time-varying space.
GPS	Global Positioning System A US space-based radio-navigation system that provides reliable positioning, navigation and timing services to civilian users on a continuous worldwide basis at no cost to users.
gyrometer	A device that measures orientation along one or more axes.

HMI	Human Machine Interface.
HVAC	heating, ventilating and air-conditioning.
identity management	The management of a user's or device's identity by a process of secure management of identity information such as credentials, identifiers, attributes and reputations. In practice, it covers a wide range of processes that include establishing, modifying, suspending, archiving or terminating identity information; recognising partial identities that represent individuals or devices in a specific context or role; and establishing or assessing trust relationships.
IEEE	Institute of Electrical and Electronic Engineers A non-profit organisation and leading professional association for the advancement of technology.
IETF	Internet Engineering Task Force.
the internet of things	The networked interconnection of objects both simple and complex.
IP	internet protocol The key member of the suite of internet protocols at the network layer, specifying packet addressing and routing data through the internet.
IPV4 and IPV6	Internet protocol global addressing schemes that enable the delivery of digital data between source and destination addresses. IPV6 is subsequent addressing scheme providing a larger address space to ensure available public IP addressing of all networkable devices.
ITU	International Telecommunication Union The leading United Nations agency for information and communications technologies, including radiocommunications, standardisation and development.
kWh	Kilowatt hour Unit of energy or consumption.
M2M	Machine-to-Machine technologies Allowing devices to communicated with each other.
MEM	Microelectronic mechanical systems.
nanotechnology	Technology using matter at an atomic and molecular scale. Also being used for the creation of materials and devices in electronics.
meteorology	One of the oldest sciences to use sensor technologies to observe, record and forecast weather. It relies on a range of sensor technologies to measure climate parameters such as temperature, humidity, pressure, solar radiation and wind speed.
passive sensing techniques	Detecting or observing natural radiation of energy reflected or emitted from objects or an area of interest.
RFID	Radiofrequency Identification.
SCaDA	Supervisory control and data acquisition A centralised system that can be used to monitor and control networked devices such as sensors and

	actuators.
sensor	A device that is directly affected by an observable physical property such as light, sound or motion to produce an intelligible signal.
smartphones	Provide advanced computing functionality beyond feature phones or PDAs. Smartphones have more powerful processors, larger displays and complete operating system software providing a standardised interface and platform for application developers.
smart metering	A device that can be used to measure a physical quantity in set time intervals and that digitally communicates the information. Forms part of a smart grid network and provides informational advantage over traditional metering systems by logging digital information and communicating to other machines or users.
Stuxnet worm	Computer worm that targets industrial software and equipment such as SCADA systems by faking industrial process control sensor signals.
transducer	A smart sensor that converts one form of energy into a direct representation of another form. Can also contain a sensor and/or an actuator.
Wifi	Wireless Fidelity Alliance Used generally to refer to wireless local area network (IEEE 802.11) technology providing short-range, high-data rate connections between portable data devices and access points connected to a wired network.
USB	Universal Serial Bus.
USN	Ubiquitous sensor networks.
vehicle telematics	Integrated use of telecommunications and sensors in vehicles to provide shared information
ZigBee	Wireless digital technology network standard based on IEEE 802.15.4 and designed for low-duty cycle transmissions, for the purpose of conveying control and measurement data.

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