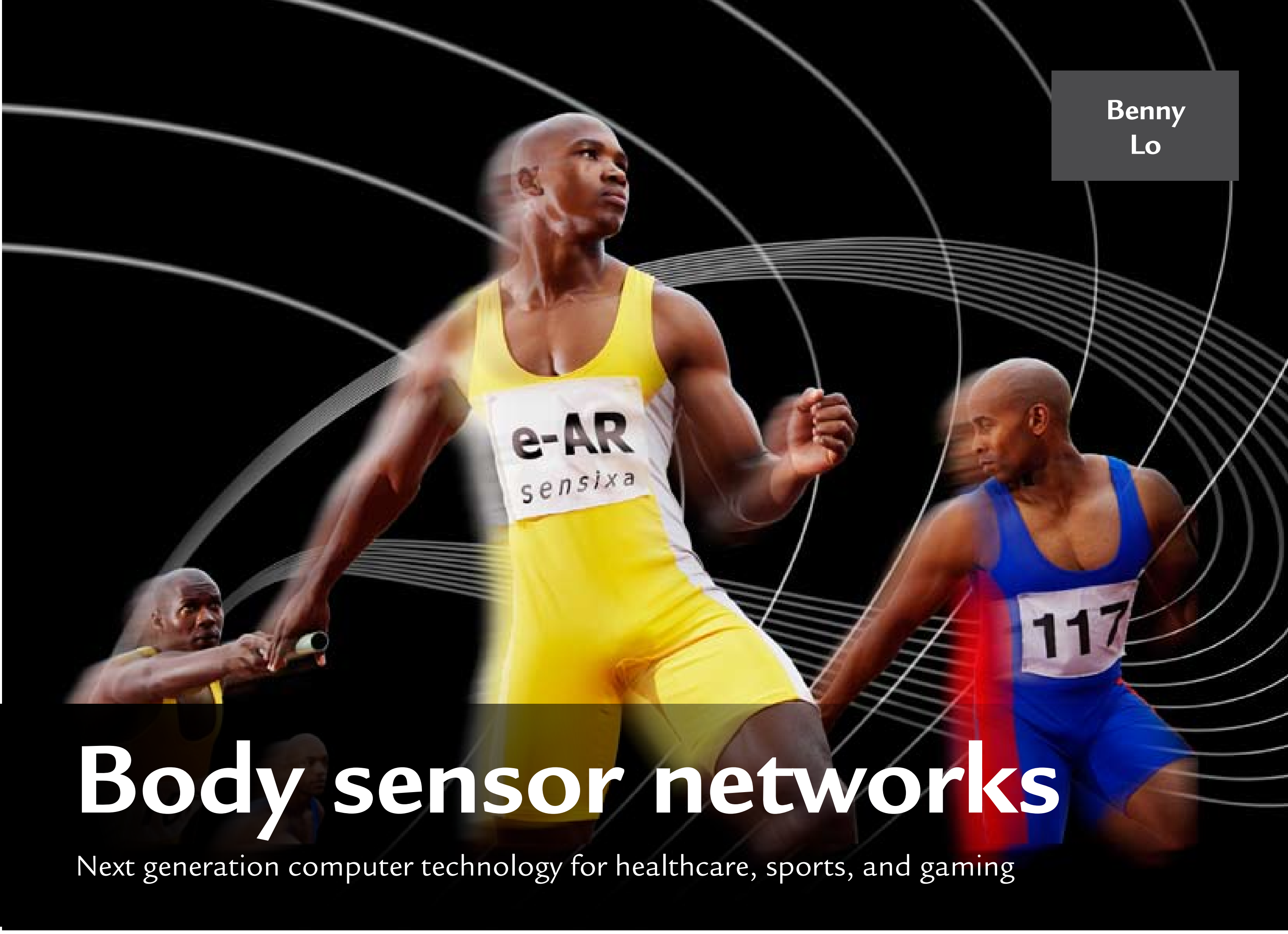


Benny Lo

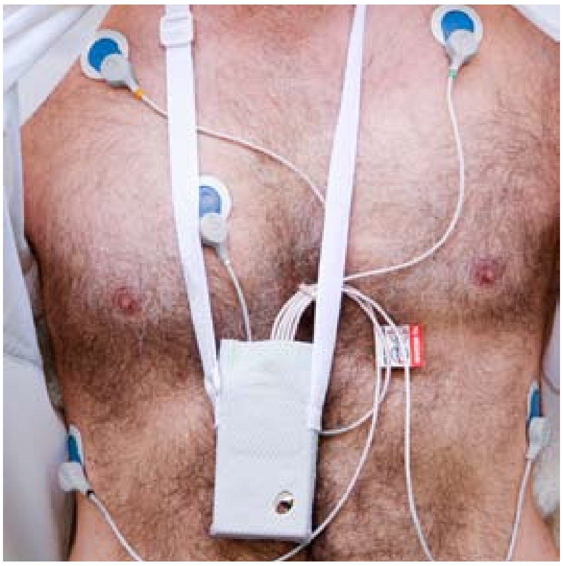
Body sensor networks

Next generation computer technology for healthcare, sports, and gaming

As electronic devices get smaller and more powerful, they are finding new uses in monitoring human activity. In this article, Dr Benny Lo of Imperial College London describes a project to develop sensors with uses in medicine, sport and electronic gaming.

Key words
sensor
processor
wireless communication

Some patients, especially patients with chronic diseases such as heart disease, require continuous monitoring of their condition. Wearable devices for patient monitoring were introduced many years ago – for instance, wearable ambulatory ECG (electrocardiogram) recorders commonly known as Holter monitors (Figure 1) are used for monitoring cardiac patients. However, these monitors are quite bulky and can only record the signal for a limited time. Patients are often asked to wear a Holter monitor for a few days and then return to the clinic for diagnosis. This often overlooks transient but life-threatening events. In addition, we don't know under what condition the signals are acquired, and this often leads to false alarms. For example, a sudden rise in heart rate may be caused by emotion, such as watching a horror movie, or by exercise, rather than by a heart condition.



Sheila Terry/SPL

Figure 1 *A patient wearing a Holter monitor (a portable electrocardiogram).*

Body sensing

To address these issues, the concept of Body Sensor Networks (BSN) was first proposed in 2002 by Prof. Guang-Zhong Yang from Imperial College London. The aim of the BSN is to provide a truly personalised monitoring platform that is pervasive, intelligent, and

The chip in your mobile phone has more computing power than the first generation of desk-top computers in the early 1980s.

invisible to the user. Figure 2 depicts an example BSN system. It represents a patient wearing a number of sensors on his body, each of which consists of a **sensor** connected to a small **processor**, wireless **transmitter**, and **battery pack**, forming a **BSN node**. The BSN node captures the sensor data, processes the data and then wirelessly transmits the information to a local processing unit, shown as a personal digital assistant (PDA) in the diagram. All this has been made possible by rapid advances in computing technology.

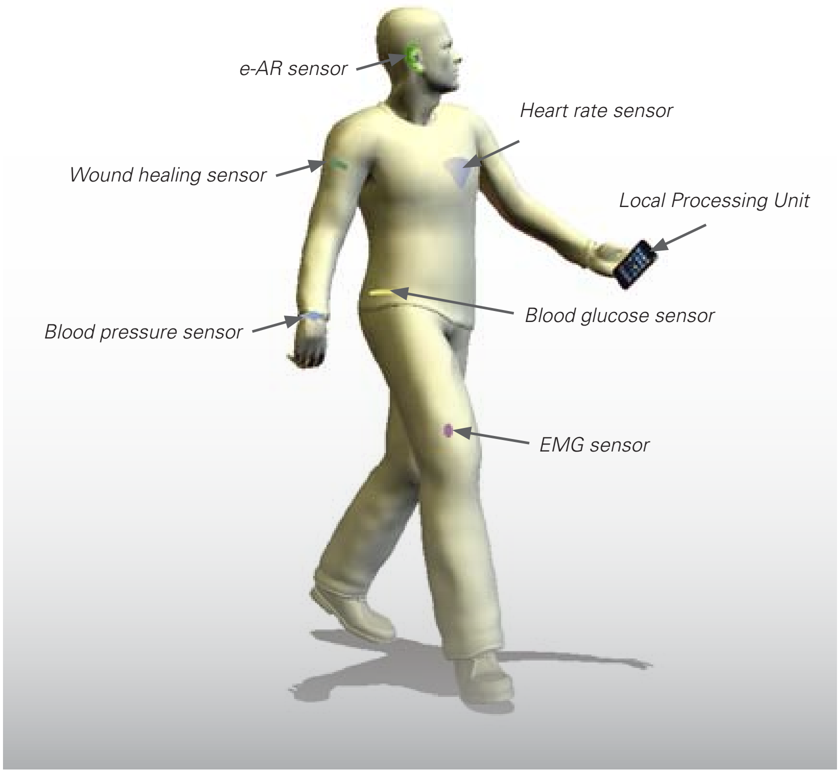


Figure 2 *An example Body Sensor Network (BSN) system*

To demonstrate the concept, different sensor nodes are depicted in the diagram. These are:

- the e-AR (ear-worn Activity Recognition) sensor (for capturing the posture, gait and activity of the patient)
- the wound healing sensor (for monitoring the progress of healing for burn patients)
- the blood pressure sensor (for measuring the blood pressure for patients with hypertension)
- the EMG (electromyography) sensor (for capturing the muscle activities of orthopaedic patients)
- the blood glucose sensor (for measuring the glucose level of diabetic patients)
- the heart rate sensor (for detecting abnormal heart conditions of cardiac patients).

Sensing activity

Following the concept of the BSN, a number of novel devices have been proposed. One example is the Imperial e-AR (ear-worn Activity Recognition) sensor. Physiological measurements, such as the body temperature and heart rate, are important. However, the mobility and activity of patients are also important indicators of health. For instance, the level of activity of a patient after surgery is often used to assess the recovery process after surgery. To enable the sensing of daily activities, the e-AR sensor was developed. Figure 3 shows the design of the sensor and how it can be worn by the user. The ear worn sensor is basically a tiny computer with a sensor and a wireless communication link.

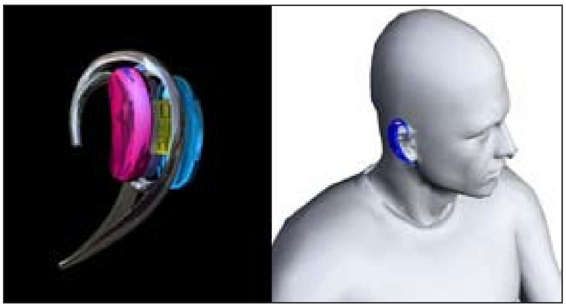


Figure 3 *The e-AR (ear-worn Activity Recognition) sensor*

The design of the e-AR sensor was inspired by the human inner ear. The human inner ear consists of an auditory system (the cochlea) and a balancing (vestibular) system, as shown in Figure 4. Within the vestibular system there are two sensory mechanisms, called the semicircular canals and the otoliths for sensing the rotational and translational motions. The semicircular canals consist of three half-circular interconnected tubes positioned in three near-orthogonal planes for sensing the three degree of rotations. Inside the canals, there are many tiny little hairs (cilia) and canals are filled with a fluid called endolymph. When the head rotates, the fluid flows along with the rotation and bends the little hairs inside the canals. This sends a signal along nerves to the brain where it is translated into the sense of the rotation. The otoliths, on the other hand, consist of the saccule and utricle for sensing the vertical and horizontal movements. Similar to the semicircular canals, the vertical and horizontal translations are also captured by tiny little hairs with fluid movements inside the saccule and utricle.

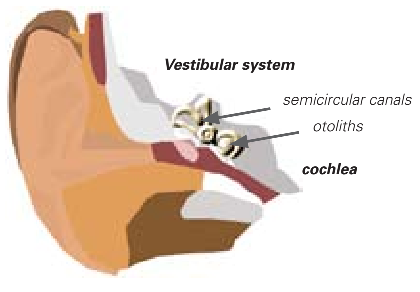


Figure 4 *Human inner ear*

To emulate the sensory functions of the human vestibular system, the e-AR sensor is equipped with a MEMS (Micro Electro-Mechanical System) 3-axis accelerometer which is capable of detecting acceleration in 3 dimensions (up and down, left and right, back and forth). An accelerometer consists of a mass, and when the sensor is moved, the mass moves. Electronic sensing components determine the acceleration. By positioning the accelerometer on the ear, the e-AR sensor can pick up similar information to the vestibular system, and this records the posture and activities of the user.

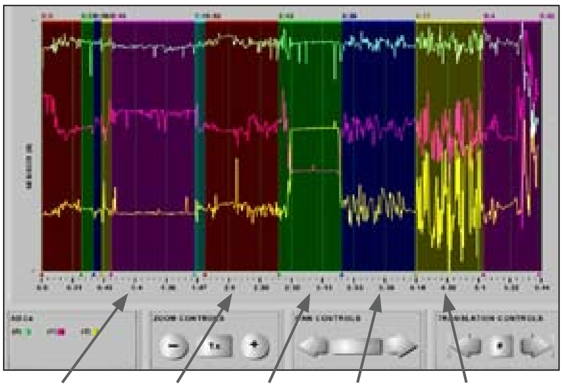


Figure 5 *The e-AR sensor's three accelerometers give three signals, shown here as three traces. Different activities give different characteristic patterns.*

Keeping it small

The main challenges for designing an ear worn sensor are the size and weight of the sensor. The sensor has to be extremely light and small, such that it can be worn comfortably by the user. Currently, the battery is the biggest and heaviest component in a sensing system. The power consumption is the most important consideration in designing the ear worn sensor. If the power consumption of the sensor can be reduced, the size and weight of the sensor can be minimised.

An ultra low power wireless transceiver (a device which can act as both a transmitter and a receiver) and a computer processor (Figure 6) are incorporated in the design of the sensor. To enable real-time monitoring, wireless communication is required, such that real-time information can be sent and viewed by the user. However, wireless communication is power demanding, and a typical wireless transceiver can take up ten times more power than the accelerometer. To reduce the power consumption, the amount of information transferred has to be reduced, hence the need for the computer processor. If the sensor can perform detailed analysis and output only the detected results, such as sending an alarm when abnormality is detected, the amount of information transferred and the energy consumption will be greatly reduced. However, due to the size and power constraint of the sensor, the on-sensor processing remains an active research topic.

Figure 6 *A prototype Application-Specific Integrated Circuit (ASIC) chip for a body-sensing node held by Prof. Guang-Zhong Yang – Imperial College London*

To study the feasibility of using the e-AR sensor for healthcare, we have conducted a number of patient trials. From the results of our pilot study on post-operative care, we have found that the sensor can allow us to monitor patients' recovery after surgery. For some patients, this means that they will be able to go home earlier from hospital; the medical team will be able to monitor their progress remotely.

Fun and games

In addition to healthcare applications, the concept of body-sensing nodes has recently been extended for well-being, sports and gaming applications. because it can gather detailed information about posture and gait, the e-AR sensor has been applied in sports applications. It has been shown that the easy-to-wear e-AR sensor can allow us to monitor athletes in their normal training environment and give a detailed analysis of their movement. In addition, a few simple games had been developed to demonstrate the design concept of the sensors and its potential functions for gaming (Figure 7). The game player wears a sensor and their movements control the game on a monitor screen.

Figure 7 *A student tries out a prototype computer game – he is wearing an e-AR sensor.*

Next developments

The next generation BSN sensor will be integrated in the form of a silicon chip of sub-millimetre size. By integrating analogue processing and digital control onto the silicon chip, significant power reduction and increase in computation power can be achieved. Such inexpensive, flexible and infinitely customisable BSN sensors will get more and more pervasive, and sooner or later they will gradually 'disappear' into the fabric of our lives.

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Look here!

More about body sensor networks:
www.sports-bsn.org

Dept of Computing, Imperial College London:
www.doc.imperial.ac.uk