Sensors in medicine

Charles B Wilson
Institute for the Future, Menlo Park, CA 94025-7020, USA
Charles B Wilson director
Correspondence to: Department of Neurosurgery, University of California at San Francisco, San Francisco, CA 94143-0350, USA wilsonc@neuro.ucsf.edu
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Sensors are devices that detect physical, chemical, and biological signals and provide a way for those signals to be measured and recorded.[1] Physical properties that can be sensed include temperature, pressure, vibration, sound level, light intensity, load or weight, flow rate of gases and liquids, amplitude of magnetic and electronic fields, and concentrations of many substances in gaseous, liquid, or solid form. Although sensors of today are where computers were in 1970 medical applications of sensors are taking off because of advances in microchip technologies and molecular chemistry.[2 3]

Summary points

Sensors are all around us

Now sensors are moving into health care

Leading the way are sensors for the monitoring of glucose and vital signs

Sensors will change the site of health care

Smart sensors will initiate an appropriate response, including treatment

Sensors have played an important role in many industries, providing the mechanical "vision" used for counting, sorting, reading, and robotic guidance. Tactile sensors, typically piezoelectric materials, generate voltage when touched, squeezed, or bent, or when their temperature is changed. Other sensors can detect specific chemical pressures and fluid levels. Cars, homes, and offices are loaded with sensors. In the short term, sensors used in medical applications will emit a signal that can be read at the point of determination or transferred by wire or wireless transmission to remote locations. Advances in microprocessor technologies have created a smart sensor that unites sensing capability and data processing in a single integrated circuit chip. The next step is combining sensing and processing with an actuator, such as microelectromechanical systems.[4 5]

Sensors at the forefront

Many sensor technologies used in industry can be applied in medicine, and in the future, as unique sensors and sensor dependent microelectromechanical systems are designed and tested, non-medical industries will adapt them for industrial applications. Within the medical world there is a broadening intersection between information technology and biotechnology, and increasingly the role of sensors, signal transducers, actuators, and micromachines will broaden too. Some examples of new generation medical sensors indicate new roles that these devices will have in many areas of health care:

- A subcutaneous system for the continuous monitoring and recording of tissue glucose concentrations in diabetic patients has just been approved in the United States. The next generation of implanted glucose sensors will give continuous values that can be read from remote hand held devices or desktops.[6-8]
- One glucose sensor that looks like a watch sits on the skin and produces small electric shocks, which open up pores so that fluid can be extracted to monitor tissue glucose concentrations.[6]
- Engineers for the Japanese company Toto have designed a toilet that analyses urine for glucose concentrations, registers weight and other basic readings, and automatically sends a daily report by modem to the user's physician.
- A new microtool can measure anatomy and movement in three dimensions using miniaturised sensors (18 mm × 8 mm × 8 mm), which can collect spatial data for the accurate reconstruction of ultrasound images of the heart, blood vessels, stomach, and other organs.
- A closed loop device (VIA Medical, San Diego, CA, USA) is now available for blood analysis of neonates in critical care units. Through an indwelling line blood is circulated through a chemistry sensor, analysed in a minute, and returned, with no loss of blood to the neonate.
- Scientists have developed a lightweight fully automatic system for the detection of biological weapons. This system uses fluorescent antibodies, diode lasers, fibreoptics, and photodetectors to find airborne bacteria.[9]
- Pathogens can also be detected by another biosensor, which uses integrated optics, immunoassay techniques, and surface chemistry. Changes in a laser light transmitted by the sensor indicate the presence of specific bacteria, and this information can be available in hours.
- An Australian team has developed a highly stable and sensitive biosensor, which operates by switching the ion channels in a lipid membrane. When activated, biological receptors such as antibodies and DNA convert a chemical event into an electric signal. One team reports it could measure the increase in sugar content of dropping one sugar cube into Sydney harbour.
- The next generation of cardiac pacemakers will become "smart" by receiving readings from various places in the body, such as oxygen saturation in the blood and cardiac wall pressure, allowing the pacemaker to adapt the heart's pacing to those real time readings.[10]
- Polymer wafers can be saturated with therapeutic agents, such as drugs or insulin.[10] In the latter case the wafer contains an enzyme that enables the wafer to change the pH and solubility of the insulin in response to changes in blood glucose concentrations. Smart wafers being tested on animals use magnetism or ultrasound to alter the dose of drug or to switch to another drug.
- Scientists and engineers at Johns Hopkins Institute have developed a biochip photosensor, which can be implanted in the eye as an artificial retina for patients with macular degeneration and retinitis pigmentosa.[10]

- Bacteria causing ear, nose, and throat infections can be instantly identified by an electronic “nose” that detects and differentiates the odours of growing bacteria.[11]
- More than 20 000 people worldwide have been implanted with auditory sensors that bypass the non-functioning parts of the hearing mechanism. The first device that successfully interfaces with the human brain has become totally implantable with a battery that is digitally programmed and rechargeable by a portable inductive charging unit.[12]

Implications

To say that sensors will have a transforming effect on health care overstates their impact in the short term but is realistic within 10 years. Sensor technology will move the place at which health care is delivered in the future, changing the roles of hospitals, outpatient sites, homes, and ambulatory programmes outside the home.

Hospital

The vent on the ceiling of the lobby will be an air monitor, which detects and reports any visitor who might transmit an airborne infection to a patient. Other sensors will be located in sinks for staff and visitors who are required to wash their hands before and after going into a patient’s room. Any carrier will be swept with a hand held biosensor,[13] which identifies the specific organism and its sensitivity pattern.

The central laboratory will no longer exist. Less frequent tests will be done at a regional facility. The bacteriology laboratory will have been replaced by hand held biosensors, some of them functioning as electronic noses and others detecting and characterising organisms in sputum, urine, and other secretions. The biochemistry laboratory will be gone too and replaced by chemical sensors worn by or implanted in every patient. For acutely ill patients similar arrays of chemical sensors will be components of infusion catheters and beds. Values can be read by authorised staff on devices at any site.

The table used in operating rooms, the gurney, and the hospital bed will be the same piece of equipment, which will be wheeled around by robots. A sophisticated life support for trauma and transport unit (LSTAT, Northrop Grumman) designed for use under battlefield conditions and commercialised after the turn of the century, was the forerunner of this mobile bed. The apparatus combines aerospace materials, information processing, and integrated systems technologies in a unit that is capable of autonomous function. Through the use of embedded sensors the bed can monitor vital signs and blood chemistries, and it is also equipped to provide, under the control of sensors, mechanical ventilation, suction, intravascular infusion, and cardiac defibrillation. The patient can remain on this unit for surgical procedures and for recovery, while being continuously monitored by smart sensors that can activate homoeostatic programmes in response to changes in the patient. A central intensive care unit will no longer be needed for monitoring patients who are acutely ill or who have had surgery, reducing the risk of cross infection.

The cardiac catheter laboratory will have entered the age of molecular cardiology. Because pharmaceuticals have reduced the incidence of atherosclerosis and can dissolve plaques and clots, the number of patients requiring coronary angioplasty has dwindled.[14] Instead, catheters directed by sensors will be used to deliver angiogenesis factors and cultivated myocardial cells to ischaemic and damaged heart muscle. A few patients are being treated with new sensor based micromachines that can remove plaque from coronary arteries.[15]

Outpatient site

Patients provided with smart pacemakers, artificial retinas, and chemical sensors will be seen in a local ambulatory primary care clinic. The physician or nurse will obtain information on line about a patient’s blood chemistries, electrocardiogram, blood pressure, and temperature. A diabetic patient will have had no diabetes related problem since having a smart glucose sensor or insulin reservoir system implanted. An elderly woman with transfusion related AIDS who seems healthy will be managed by a smart viral count sensor integrated with an implanted reservoir containing a drug. A smart sensor or drug reservoir system will be equally effective in the management of a patient whose dysfunctional manic depressive illness is now modulated by chemical sensors that detect the initial chemical imbalance and actuate the injection of appropriate drugs.

Home health care

Telemedicine and sensor technologies will have moved the outpatient laboratory and the doctor’s surgery into the living room. Interactive video conferencing, educational programmes, and a broad range of sensors will provide health care at a distance. Patients will not need to tell nurses their weight because it, vital signs, and blood chemistry values will be seen by the nurse on a hand held device. The nurse will be able to inform patients whether their toilet reported bacteria in their urine, and the pharmacy will deliver a prescription accordingly.

Ambulatory treatment

Smart blood pressure sensors will manage the drugs for patients with hypertension, sending an immediate alert to the central monitoring unit when integrated sensors for cardiac function and vital signs indicate an unexpected problem. Episodes of diarrhoea in patients with an irritable bowel syndrome will be detected as they begin to evolve and patients will be able to terminate these abruptly by pressing a drug filled subcutaneous reservoir.

Final thought

Within 10 years biosensors will cause changes in sites of care and the configuration of delivery systems. In many cases the quality of care will be improved and patients can be managed in their homes. Hospitals will operate differently, as well as more safely and efficiently. These advances will, however, be expensive and in many parts of the world irrelevant. New and better vaccines for preventing common conditions afflicting many millions throughout the world would be a far greater benefit to humankind than all the sensors that will be developed and manufactured in the next decade. The contrast between the upper socioeconomic classes with access to sophisticated medical technologies and the lower socioeconomic classes that continue to bear unnecessary morbidity and mortality underscore eliminating health inequities as one of our highest priorities.

Competing interests: None declared.

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