Southwest Center for Microsystems Education (SCME)
University of New Mexico

MEMS for Environmental and Bioterrorism Applications

Learning Module

This Learning Module contains the following units:
Primary Knowledge (PK) Reading material
Research Activity
Final Assessment

This learning module provides an overview of how MEMS (MicroElectroMechanical Systems) are being used for bioterrorism and environmental sensing. An activity allows for more in-depth exploration into an application of personal interest.

Target audiences: High School, Community College, University

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Website: www.scme-nm.org

MEMS for Environmental and Bioterrorism Applications
Primary Knowledge (PK)
Instructor Guide

Note to Instructor

This Primary Knowledge (PK) unit provides introductory material on the applications of Microelectromechanical Systems (MEMS) for environmental and bioterrorism sensing. This PK and its related activity and assessment are part of the *MEMS for Environmental and Bioterrorism Applications Learning Module*:

- **MEMS for Environmental and Bioterrorism Applications PK**
- MEMS for Environmental and Bioterrorism Applications: Activity
- MEMS for Environmental and Bioterrorism Applications Assessment

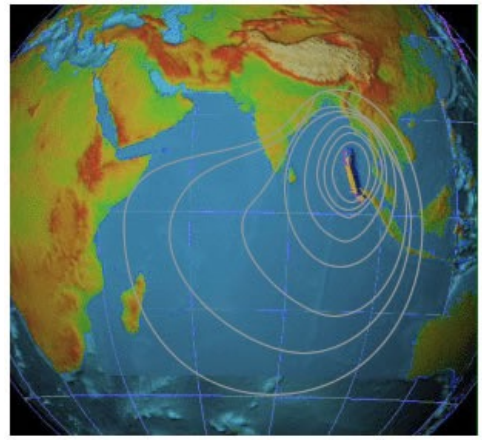
Description and Estimated Time to Complete

This learning module provides an overview of how MEMS (MicroElectroMechanical Systems) are being used for bioterrorism and environmental sensing. An activity allows for more in-depth exploration into an application of personal interest.

This unit introduces you to MEMS applications for environmental and bioterrorism sensing. You will identify several reasons that such sensing devices are needed, as well as the types of MEMS that are currently used or being tested for such applications.

Estimated Time to Complete
Allow at least 30 minutes to review this material and answer the questions.

Introduction



Indian Ocean Earthquake

[Modified image from U.S. National Oceanic and Atmospheric Administration]

On 26 December 2004, a massive earthquake of magnitude 9.0 struck the coastal area off northern Sumatra in Indonesia. (See graphic) A number of aftershocks occurred, some of magnitude 7.1. These earthquakes triggered a series of tsunamis in the Indian Ocean that affected Indonesia and neighboring countries in Asia (including India, Malaysia, Maldives, Sri Lanka, and Thailand), and the east coasts of Africa (including Somalia and Yemen). These countries suffered serious damage to the coastal areas and small islands.

While the final death toll will never be known, an estimated 250,000 people in eleven countries perished, the majority of them women and children. Millions more people have been displaced or rendered homeless. The damage from the tsunamis was particularly severe as a large percent of the population, and many key cities and towns, lie within 50 km of the ocean edge. The question that has been asked a thousand times since the tsunamis hit is
"Why weren't people warned?"

2004 Tsunami in Ao Nang, Thailand.

[Permission to use by author: David Rydevik]

The tsunamis were detected by geophysicists at the Pacific Tsunami Warning Centre (PTWC) in Honolulu, Hawaii. The PTWC did inform several agencies in countries on the Indian Ocean. However, because there was no detection system in the Indian Ocean, nor was there a communication system in place for people living along the coasts, this warning never reached the people. As a result, many lives were lost.

Microelectromechanical Systems (MEMS) sensors have been found to be part of the answer to an effective warning system. MEMS accelerometers (like the ones in airbag deployment) and MEMS hydrophones are being use in seafloor seismic recording systems[1] as well as seismic sensors for the oil and gas industry[2]. In this unit you will learn about these sensors and other MEMS sensors that are used and being developed for environmental applications and bioterrorism.

Objectives

- Discuss at least three ways that MEMS are currently being applied to environmental or bioterrorism sensing.

- Develop at least two ideas for possible MEMS applications in environmental or bioterrorism sensing.

MEMS Sensing

Environmental and bioterrorism sensing has always been important. However, after certain cataclysmic events such as the Indian Ocean tsunami in 2004, 9/11, the prospect of human-caused climate changes, and the need for more energy sources, targeted sensing has become a necessity for individuals and governments. MEMS sensors can help protect and preserve life on earth as we know it by doing the following:

- Monitor weather and other environmental conditions, including agriculture and ecological concerns.
- Monitor energy, fluid, machinery, and other systems in factories, facilities, buildings and homes as well as the structures themselves.
- Sense transportation vehicles and related transportation infrastructure including roads, bridges, and equipment.
- Sense potential security and safety problems in buildings, factories, airports, and war zones (to name a few).

In this unit, several examples of how MEMS technology can be applied are presented. Their uses and applications on land, in air, or in water or a combination of the three are discussed.

Marine Environment

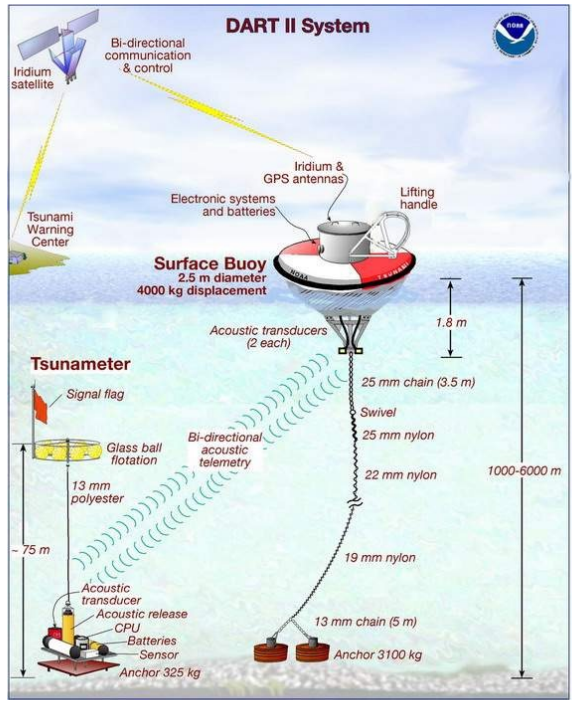
Parameters commonly measured in the marine environment are
- temperature,
- pressure,
- light,
- tidal and current velocity,
- plant pigmentation (chlorophyll in plankton),
- dissolved gases,
- pH,
- metal concentration,
- pesticide concentration, and
- seabed characteristics such as seismic signals.

MEMS sensor technology is being used to sense and monitor many of these parameters. Following are some examples of this technology.

Tsunami Warning System

The objective of a warning system is to continuously monitor the state of the sea surface in near-real time. This allows for a fast and efficient warning to be issued through the correct channels. A warning system consists of three components:

- scientific instrumentation
- communication system
- warning system



Graphic courtesy of the National Oceanic and Atmospheric Administration

The scientific instrumentation is an assortment of sensors designed to detect various ocean activity. Pressure, current, velocity and seismic sensors are the types of sensors used in an effective tsunami warning system.

Some sensors target the tsunami wave over different ocean depths by measuring wave height. In order to do this effectively, the sensitivity of these sensors must be sufficient enough to detect changes in wave heights of a few decimeters over deep ocean. In addition, all other environmental factors affecting the sea level (tides, atmospheric pressure, wind) must be understood and monitored in order to separate these signals from the tsunami wave.

The wavelength of tsunami waves is different from wind-driven and tidal waves. This allows for the identification of a tsunami by using spectral analysis, a process that identifies variation in cyclic components over a period of time. For example, ocean waves consist of different frequencies and amplitudes that are normally stable and predictable. Spectral analysis uses wave height versus time to determine the normal frequencies and identify changes or abnormalities.[3]

Once the observations of seafloor bottom pressure sensors, Global Navigation Satellite Systems (GNSS), and tide gauges or satellites have been collected, a fast transmission of the data to a processing center is required. For this purpose, radio transmission from a buoy to a land station is used. If the distance between the two antennas is greater than about 50 km, a satellite link is established. The processing centers at the land station analyze the incoming data and detect potential sources of tsunamis (e.g., from seismological networks), and combine this with the received observations. The results are the basis for the activation of a warning system.

At present, there are two tsunami warning systems in place:

- Deep-ocean Assessment and Reporting of Tsunamis (DART) system of the National Oceanic and Atmospheric Administration (NOAA). As of March 2008, the United State's complete system of 39 units (seafloor bottom recorders and buoys) had been installed in the Pacific, Atlantic and Caribbean Oceans. Since 2009, Australia, Chile, Thailand, and Indonesia have incorporated DART buoy systems into their tsunami systems. (See the previous graphic of the Dart II System)
- German and Indonesian Tsunami Early Warning System (GITEWS) - The GITEWS is focused on the Indian Ocean in response to the Indian Ocean tsunamis. This system was put into operation in November, 2008.[4]

A U.S. Indian Ocean Tsunami Warning System (USIOTWS) is also under consideration by a group of countries lead by the USA.

The GITEWS

The GITEWS consists of multiple sensors for a comprehensive monitoring of seismic activity, water pressure, sea level and meteorological data. The principal components of GITEWS are ground sensors, a GNSS (Global Navigation Satellite Systems) buoy and an ocean bottom pressure gauge. A space sensor is used as a radar altimeter. Communication systems are radio and satellite links from the sensors to a land-based Tsunami Warning Center (TWC).

MEMS Ocean Sensors

Other MEMS sensors are being developed to monitor changes in the ocean's temperature and light penetration.

Temperature Sensors

Monitoring the ocean's temperature is important because an increase in temperature decreases oxygen concentration. It also decreases solubility of some minerals and salts. This is extremely important for aquatic life.

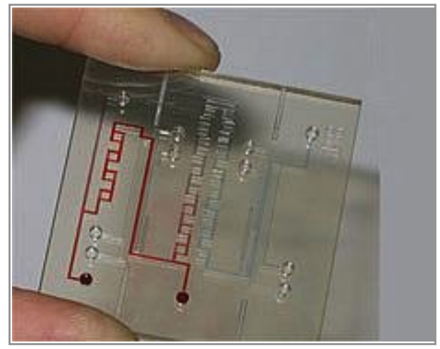
Light Sensors

Decreased light penetration affects algal and marine plant growth. It also indicates the presence of silt and other light absorbing or reflecting compounds in the water.

Attachments Devices

MEM devices in the water can be attached to a variety of objects:

- ships
- floating devices (buoys)
- fixed objects such as rigs
- anchors on the bottom of the ocean or river
- AUVs (automated underwater vehicles)



AUVs are unmanned underwater vehicles for real time monitoring in the oceans. AUVs can be equipped with "Lab on a Chip (LOC)", a set of sensors developed on a single chip, using MEMS technology. "Lab on a Chip" devices can sense a large number of chemical pollutants simultaneously.

This first generation of miniaturized sensors that will measure the marine environment has been built to withstand conditions in the open ocean. (Image courtesy of the National Oceanography Centre, Southampton)

Water and/or Land Environment

Cleanup

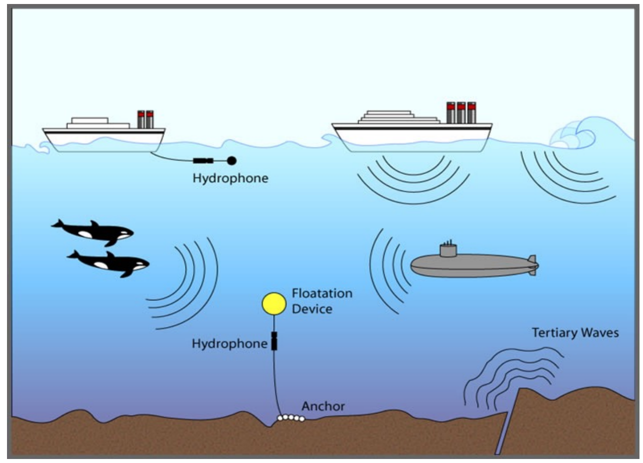
MEMS devices (e.g., pressure sensors) can be used to detect oil leakage from pipelines. In the case of unfortunate oil spills, they can sense information about the ocean currents to predict how far the oil slick can travel. This information helps in the cleanup planning process. Polypropylene microfiber bags, sheets, and inserts are being used to absorb oil while repelling water. Such products are able to absorbs up to 25 times their weight in oil and other petrochemicals.[15]

Locating Oil and Gas Reserves

MEMS geophones and accelerometers can sense the vibrations sent up from the earth's belly. An array of MEMS geophones is planted over a wide area on the seabed. Vibrations are intentionally produced on the ground surface. The MEMS devices measure the reflection of these vibrations from different layers in the earth's belly. These readings are used to create a geological map, which indicates the size and location of the oil/gas reservoir.

Hydrophones

Just as microphones collect sounds in air, hydrophones are small devices that detect sounds in water. A hydrophone could be anchored to the ocean bottom or dragged behind a ship. The hydrophone "hears" the sounds in the water – such as sound generated by ships, submarines, ocean waves or marine animals. They also "hear" tertiary waves created by earthquakes or any movements within the earth's crust.



Hydrophone Ocean Sensors

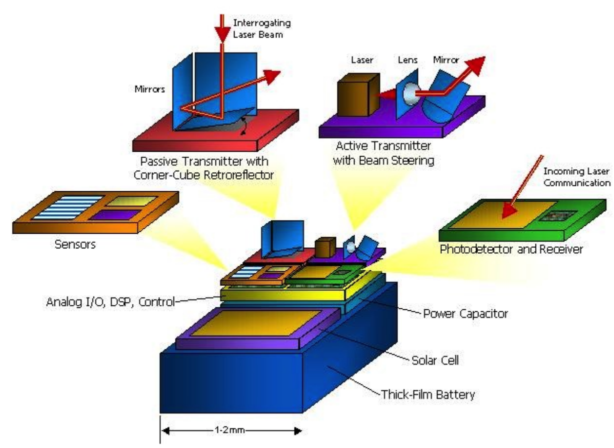
Animal Tags

These are tiny devices attached to animals like whales and deer. They provide vital data about the surroundings and about the animal. These tags contain MEMS devices that monitor a pressure, temperature, or sound. They also work as a camera or radio transmitter for data collection at remote locations.

Smart Dust

Smart Dust is a network of micro-sized wireless MEMS sensors that communicate with each other through tiny transmitters. In 1996 Dr. Kristofer S.J. Pister coined the phrase "Smart Dust" to describe his work in ubiquitous wireless sensor networks. [4,5]

The idea is for smart dust technology to be used to develop wireless sensor networks that detect and monitor an endless number of parameters like light, temperature, vibrations, and movement. Each sensor in the network is called a mote and is the size of a grain of sand or dust particle (thus the phrase "smart dust"). A smart dust network contains several sensors, computing circuits, bidirectional wireless communications technology and a power supply. Motes gather data, run computations and communicate, using two-way band radio, with other motes at distances approaching 1,000 feet. When clustered together, motes automatically create highly flexible, low power networks.



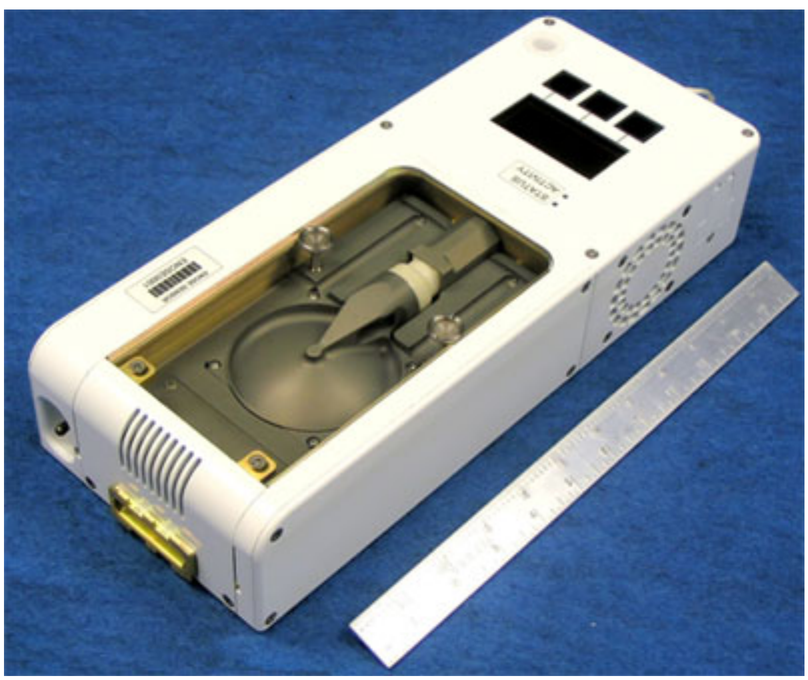
Smart Dust Mote Conceptual Diagram [Courtesy of Kristofer S. J. Pister. (DARPA) DABT63-98-1-0018 (ended) and National Science Foundation]

Smart dust could be scattered around a building, a piece of property, embedded in clothing, or in roadbeds. Strategically placed, these devices could track the movements of persons or animals, detect the presence of poisons, toxins, or biological agents in the air, or monitor household power consumption and contributors, checking for the best efficiency. "Other applications could include inventory control, smart body suits (temperature, humidity, and environmental comfort sensors sewn into clothes) and interfaces for the disabled." [6] Existing applications include networks that monitor the vibrations of machinery on a British Petroleum oil tanker to the efficiency of the refrigerators in a Supervalu grocery store.[7]

Since the 1990's technology has enabled smart dust to become smaller and smaller to the point where is it actual "dust" – micro, and even nano-size dust. At that size it could be suspended in the atmosphere to monitor or evaluate air quality or absorbed into the bloodstream for constant monitoring of one's health. Even though such devices are now possible and a lot of research has gone into smart dust, it is still considered an emerging technology.

Air Environment

The Electronic Nose, otherwise known as the ENose, senses a variety of gases, compound or combination of compounds. An ENose, developed by NASA (image below), was tested on the International Space station for 6 month in 2008. During this test "the ENose identified formaldehyde, Freon 218, methanol and ethanol, but all of them were at harmless levels."[9]

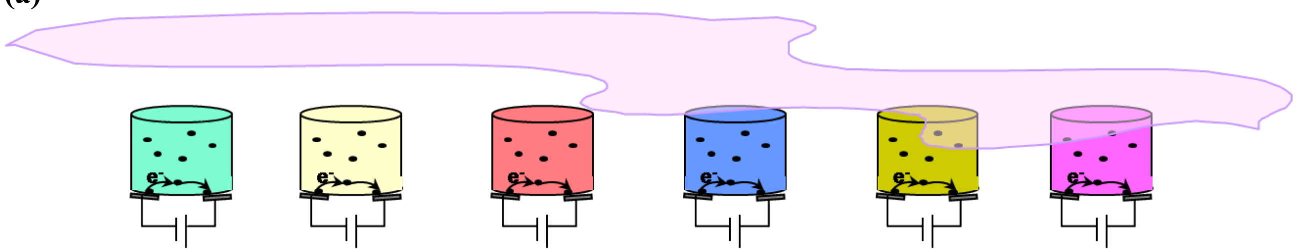


The ENose developed by NASA's Advanced Environmental Monitoring and Control division [Graphic courtesy of NASA]

The ENose has numerous medical, industrial and commercial applications such as environmental monitoring, quality control, food processing and medical diagnosis.[8] The ENose has been "used in a variety of commercial agricultrual-related industries, including the agricultural sectors of agronomy, biochemical processing, botany, cell suture, plant cultivar selections, environmental monitoring, horticulture, pesticide detection, plant physiology and pathology. Applications in forestry include uses in chemotaxonomy, log tracking, wood and paper processing, forest management, forest health protection, and waste management."[16]

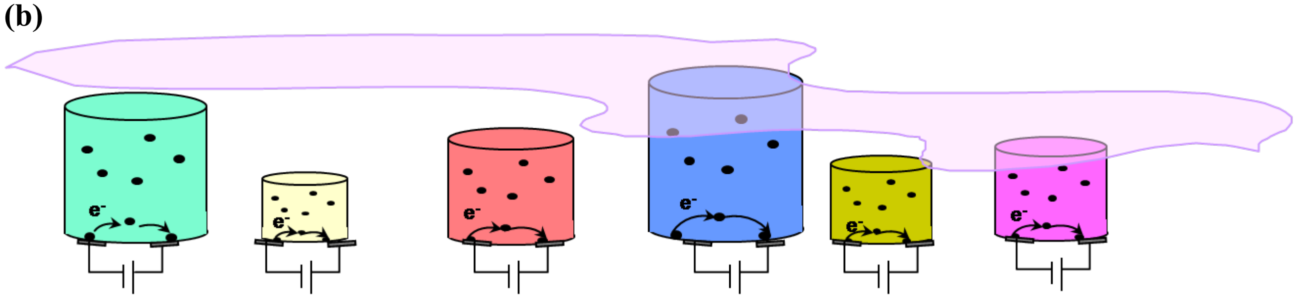
How the ENose Works [(7)]

(a)



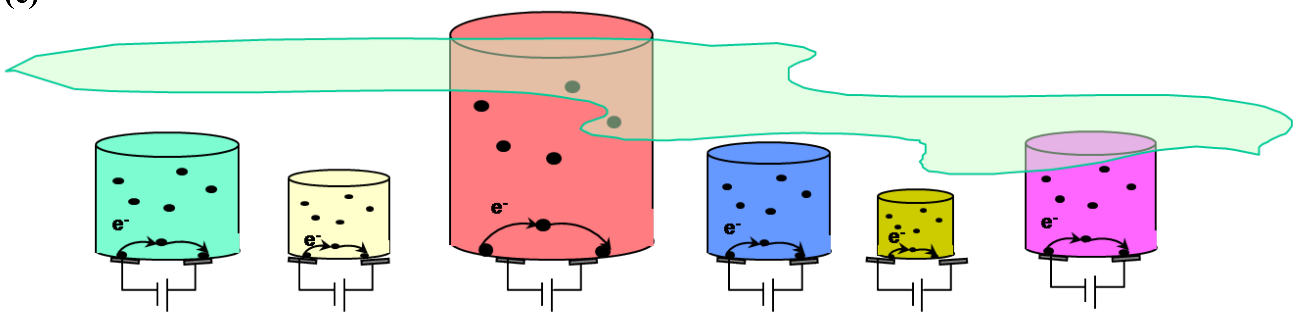
One type of ENose uses a collection of 16 different polymer films on a set of electrodes. The graphic (a) illustrates six films/electrodes. These films are specially designed to conduct electricity based on its resistance. A baseline resistance reading is established (a) with no odors (ambient air). When a substance -- such as the stray molecules from an ammonia leak -- is absorbed into these films, the films expand slightly (b), changing their resistivity. The change in resistivity then causes a change in electrode current.

(b)



Because each film is made of a different polymer, each one reacts to a chemical compound in a slightly different way. While the changes in resistivity in a single polymer film would not be enough to identify a compound, the varied changes in 16 films produce a distinctive, identifiable pattern for a specific compound. Graphic (c) shows a different compound being sensed.

(c)



[Graphics: NASA's Advanced Environmental Monitoring and Control division]

An ENose can also use a microcantilever array like the one developed at Los Alamos Laboratory. The device operates using an array of silicon microcantilevers. Each microcantilevers has a chemically selective polymer coating. When the polymer coating absorbs vapor, the surface swells and bends the cantilever. The pattern of deflection across the array indicates a unique chemical signature. [10]

Cybernetic Insects

Cybernetic Insect

Cornell University Laboratory for Intelligent Machine Systems has developed cybernetic insects for the purposes of living surveillance and reconnaissance micro-air vehicles, (MAVs). By eliminating the energy needed for flight and focusing energy efforts on controller and sensor packages, a cybernetic MAV, or CMAV, can be harnessed for the purpose of long endurance stealth missions.[11] So the next time you notice a group of dragonflies hanging around you, maybe you should take a closer look at them!

In the meantime, while researchers are working on developing the cybernetic insert, other research and actual application is being made in using live insects to gather information. Researchers have found that grapheme and carbon nanotubes can be melded together into a single mesh and used as a flexible electronic device than can interface with living insects. This device along with micro and nano-sized sensors can be placed on the back of a stag beetle, for example, and let loose into the environment to detect a wide variety of environment and air-borne issues.[17]

Hybrid Insect MEMS (HI-MEMS) Program

DARPA Microsystem Technology and a few other research facilities are taking the Cybernetic Insects one step further by taking MEMS directly to living insects. The aim of the program is to implant MEMS into an insect at the earliest developmental stage, such as the caterpillar or pupae stage. This would allow for a reliable and stable tissue and machine interface as the insect grows. The implanted MEMS will contain a control system as well as sensing devices. The objective is to control the locomotion of the insect, determining its flight path. With this type of control, the insect could be directed into specific target destinations where the MEMS sensors gather information on the desired parameters.[11]

New research at North Carolina State is attempting to "accelerate the development of cybernetically modified "biobot" moths." Swarms of these moths could be "deployed as a flying sensor network for surveillance or disaster response." The N.C. State method is to attach "electrodes to a moth during the pupal stage, in the cocoon. As the caterpillar is undergoing metamorphosis into the winged adult stage, the sensors embed themselves in such a way that researchers can directly monitor the electrical signals in muscle groups the moth uses during flight."[18]

Food for Thought

- What are some other applications for seismic MEMS sensors?
- What are some applications for the ENose that were not discussed?
- Name some applications of MEMS sensors that could benefit military personnel.

Glossary of Key Terms

Plankton – Single cell photosynthetic organism that lives in the ocean; responsible for generating most of the oxygen available worldwide.

Time series –A defined measurement made over time

Tsunamis - Large sea waves caused by large scale displacement of the ocean's water. Tsunamis can be caused by any underwater movement or explosion (earthquake, volcanic eruption) that causes a large displacement of water.

Summary

MEMS technology is used for environmental and bioterrorism sensing based on perceived risk and need. In this century, the most common sensors are pressure (including flow rate and acoustical), temperature, radiation, chemical, and biological. These sensors can be coupled together and transmit data via wireless networks to sites where the data is analyzed.

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Related SCME Units

- MEMS for Environmental and Bioterrorism Applications: Activity
- MEMS for Environmental and Bioterrorism Applications Assessment

Disclaimer

This Learning Module was developed in conjunction with Bio-Link, a National Science Foundation Advanced Technological Education (ATE) Center for Biotechnology @ www.bio-link.org.

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