MEMS FOR ENVIRONMENTAL AND BIOTERRORISM

Cybernetic Insect

Unit Overview

This unit introduces you to MEMS (MicroElectroMechanical Systems) 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.

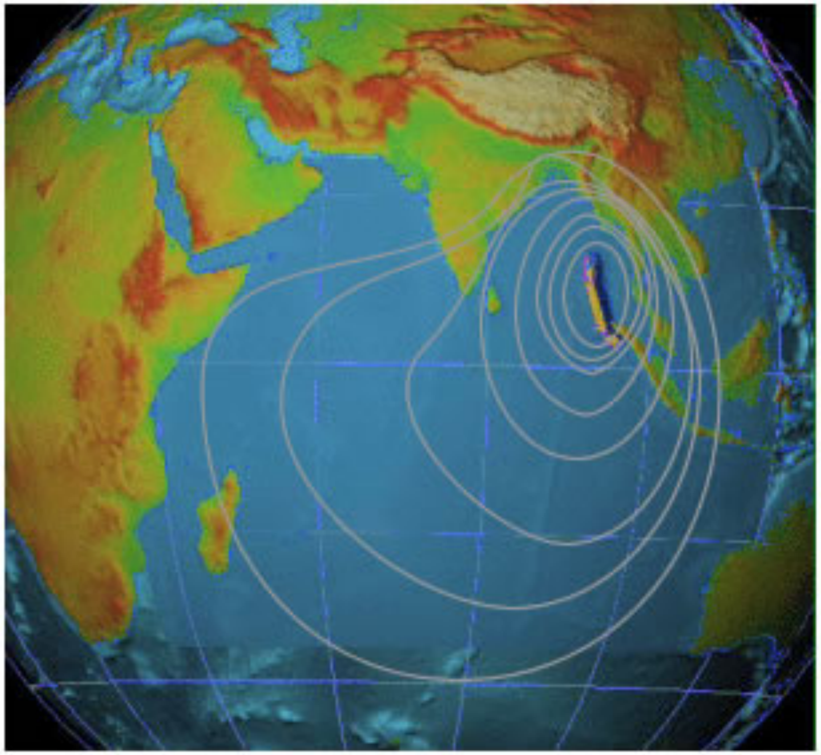
Objectives

- 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.

Introduction

December 26, 2004, a 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 affecting Indonesia and neighboring countries in Asia and the east coasts of Africa. All countries suffered serious damage to the coastal areas and small islands.



Indian Ocean Earthquake

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

Tsunami's Effect

While the final death toll will never be known, an estimated 250,000 people in eleven countries perished.

The question that has been asked a thousand times since the tsunamis hit is

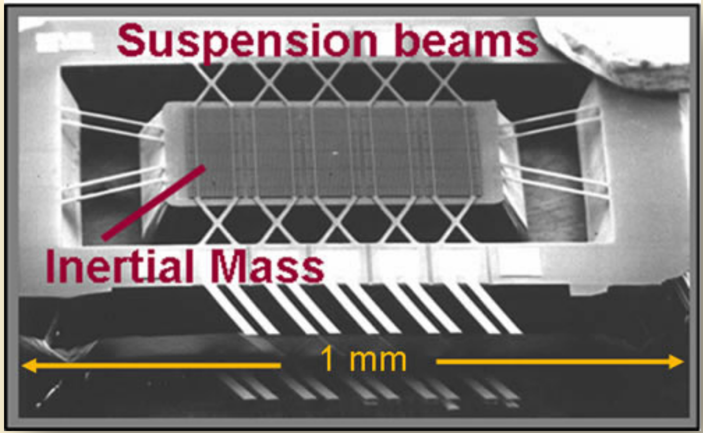
"Why weren't people warned?"

2004 Tsunami in Ao Nang, Thailand.
[Permission to use by author: David Rydevik]

Lack of Indian Ocean Warning System

- 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.

MEMS Sensors



MEMS Accelerometer - The inertial mass is deflected from its nominal position as a result of acceleration. This deflection of the mass is converted to an electrical signal as the sensor's output.

[Photo courtesy of Khalil Najafi, University of Michigan]

- MEMS sensors have proven to be part of the answer to an effective warning system.
- MEMS accelerometers (like the ones in airbag deployment units and the one above), MEMS pressure sensors, and MEMS hydrophones are being integrated into various warning systems.

MEMS Sensing

MEMS sensors help protect and preserve life on earth 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 and is being applied are presented here.

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),
- pH,
- pesticide concentration, and
- seabed characteristics such as seismic signals.

MEMS sensor technology is used to sense and monitor many of these parameters.

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.

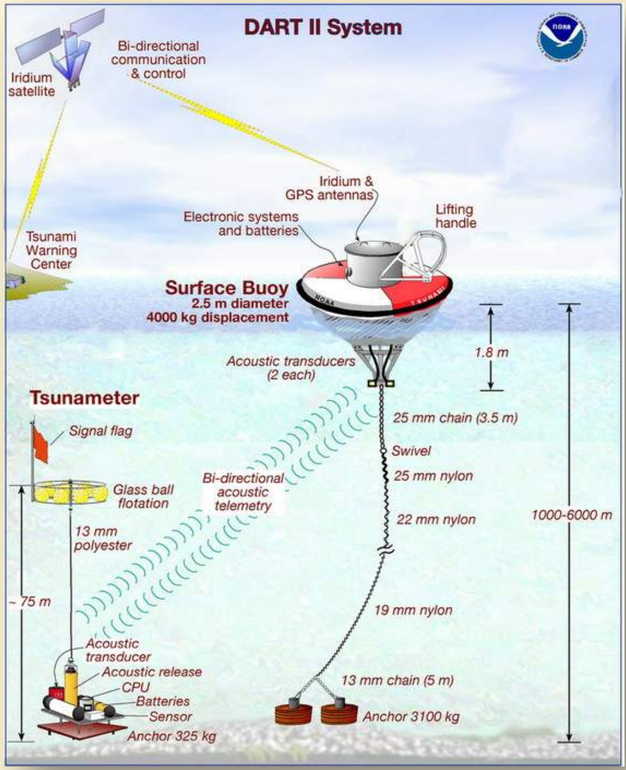
A warning system consists of three components:

- scientific instrumentation
- communication system
- warning system

Tsunami Warning System

- The scientific instrumentation is an assortment of sensors designed to detect various ocean activity. Some sensors target the tsunami wave over different ocean depths by measuring wave height.
- Additional sensors detect other environmental factors affecting the sea level (tides, atmospheric pressure, wind). These factors must be understood and monitored in order to separate their signals from the tsunami wave and other ocean waves.

The graphic illustrates the DART system with a total of 39 sensors in the Pacific, Atlantic, and Mediterranean Oceans.

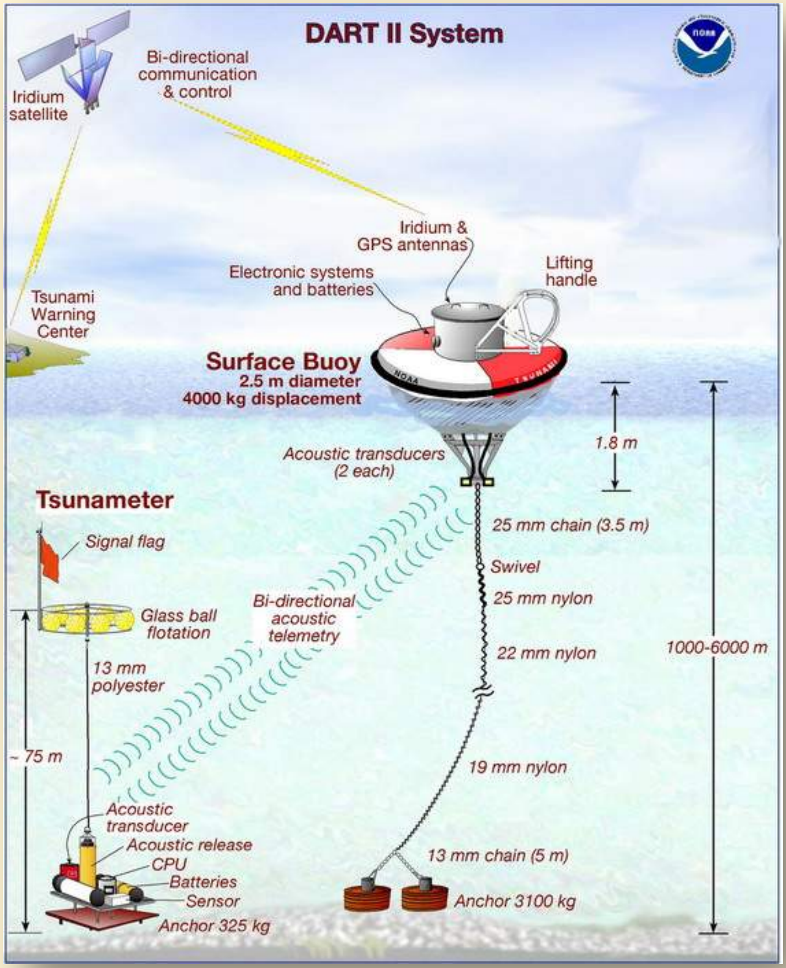


Graphic source: National Oceanic and Atmospheric Administration

How It All Ties Together

Once the data from the sensors, Global Navigation Satellite Systems, and tide gauges have been collected, a fast transmission of the data is sent to a processing center. Radio transmission are sent from a buoy to a land station. A distance greater than about 50 km between antennas require a satellite link.

Processing centers analyze the incoming data and detect potential sources of tsunamis and if a warning is required.



Current Tsunami Warning Systems

Deep-ocean Assessment and Reporting of Tsunamis (DART) system of the National Oceanic and Atmospheric Administration (NOAA). As of 2008, 39 sensors/buoys have been placed in the Pacific, Atlantic and Mediterranean Oceans. *(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.

Other MEMS Ocean Sensors

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.

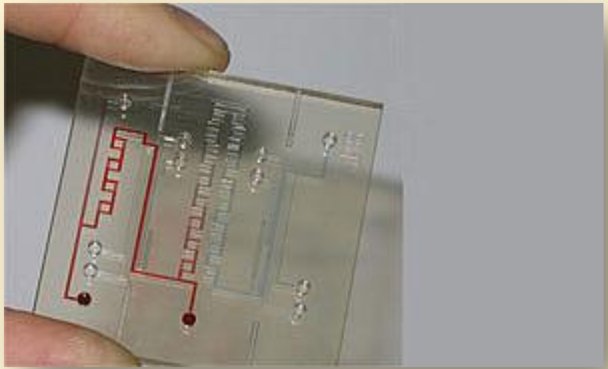
Attachment Devices for Ocean Sensors

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 and Lab-on-a-chip (LOC)

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 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 credit: National Oceanography Centre, Southampton) ScienceDaily.

Water and Land Environments

<u>Clean Up</u>

- MEMS devices (e.g., pressure sensors) can be used to detect oil leakage from pipelines.
- In the case of unfortunate oil spills, they sense information about the ocean currents to predict how far the oil slick can travel. This information helps in the clean up planning process.

Water and Land Environments

<u>Locating Oil and Gas Reserves</u>

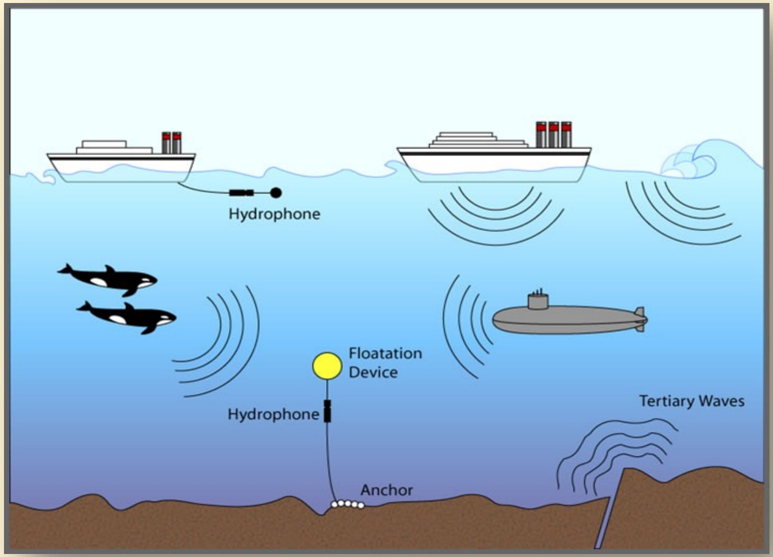
MEMS geophones and accelerometers can sense the vibrations sent up from the earth's belly.

- An array of MEMS geophones are planted over a wide area on the seabed.
- Vibrations are intentionally produced on the ground surface.
- MEMS devices measure the reflection of vibrations from different layers in the earth's belly.
- 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 detect sounds in water.

- A hydrophone could be anchored to the ocean bottom or dragged behind a ship. It "hears" the sounds in the water, sounds generated by ships, submarines, ocean waves or marine animals.
- A hydrophone can "hear" tertiary waves created by earthquakes or any movements within the earth's crust.



Hydrophone Ocean Sensors

Animal Tags

Tags 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

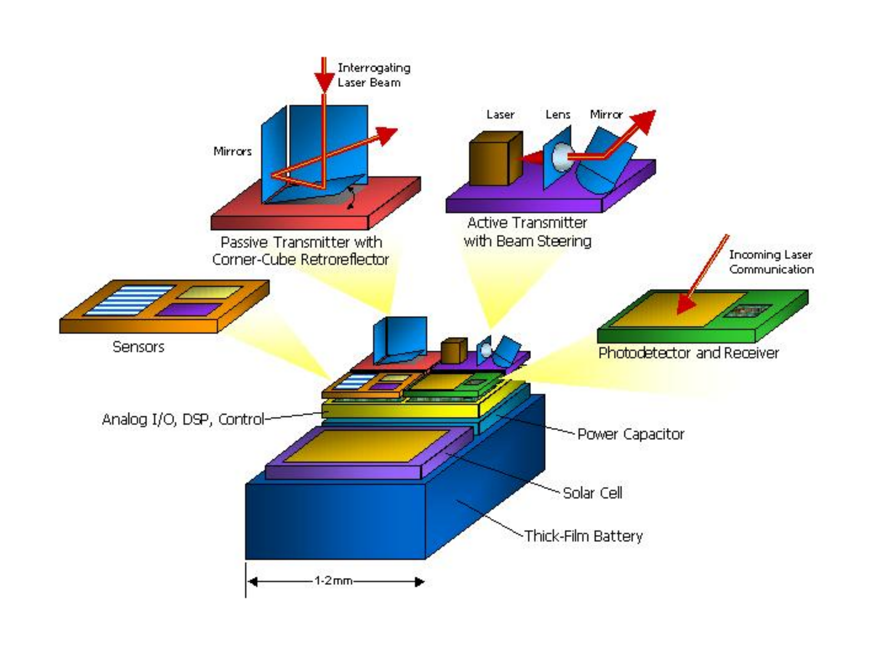
Smart Dust is a network of micro-sized wireless MEMS sensors that communicate with each other through tiny transmitters.

These wireless sensor networks are being developed to detect and monitor an endless number of parameters like light, temperature, vibrations, and movement.

Smart dust can be incorporated into roads and bridges or suspended in the atmosphere to evaluate the make of air.

Smart Dust

- Each sensor in the network is called a mote and is the size of a dust particle.
- A 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
Project through Berkeley,
DARPA and
National Science Foundation
Brett Warneke, Mike Scott, and Brian Leibowitz

Applications of Smart Dust

What do you think are some possible applications of smart dust?

Air Environment – the ENose

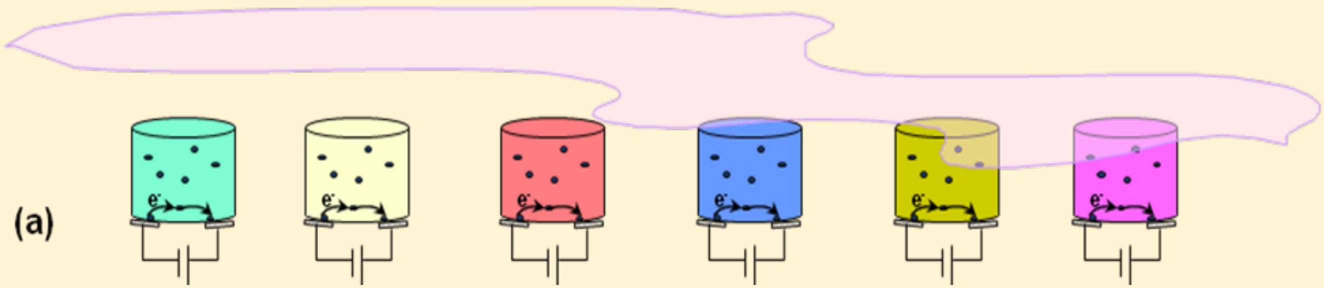
- One Enose (electronic nose) senses a several gases, compound or combination of compounds at one time.
- An ENose is being used by NASA on spacecraft to alert the crew to dangerous leaks such as ammonia and to evaluate the quality of the air.
- The Enose has numerous medical, industrial and commercial applications such as environmental monitoring, quality control, food processing and medical diagnosis.

ENose

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

The picture is the ENose developed by NASA and tested on the International Space Station in 2008. Since then its size has shrunk and its applications, expanded.

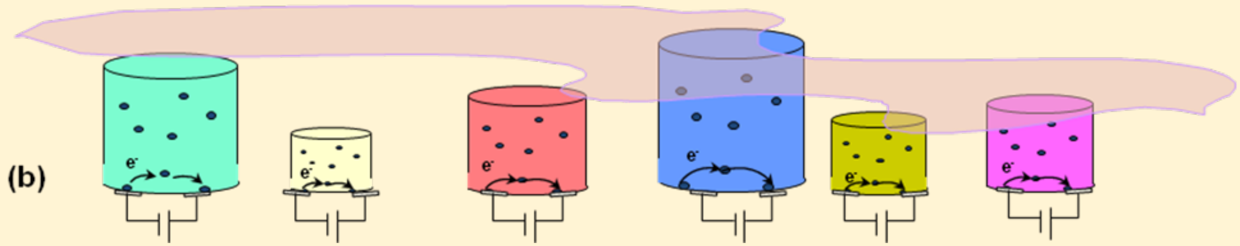
How the ENose Works



Six (6) films or electrodes in reference state (no odors)
[Graphics: NASA's Advanced Environmental Monitoring and Control division]

The 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).

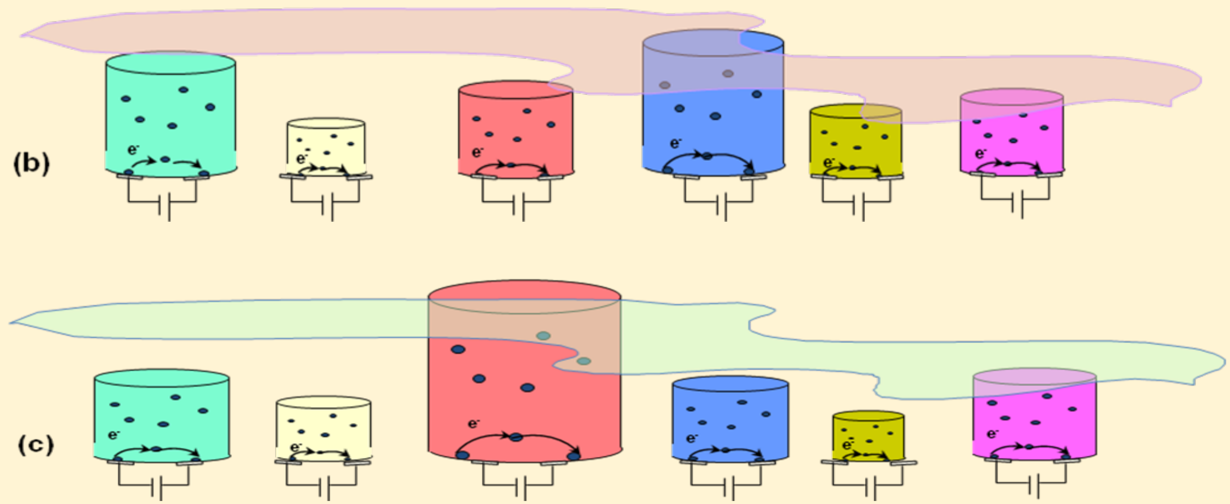
How the ENose Works



Films reacting to the presence of a odor or gas
[Graphics: NASA's Advanced Environmental Monitoring and Control division]

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.

How the ENose Works



Because each film is made of a different polymer, each 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. Graphics (b) and (c) shows two different compounds being sensed.

Cybernetic Insects

Research is taking place for the development of

- cybernetic insects and
- genetically modified insects that mature around an implanted sensor.

Such insects can be used for surveillance and reconnaissance micro-air vehicles (MAVs), evaluating air quality, and collecting and evaluating environmental particles.

Cybernetic Insect

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.*

Summary

MEMS technology is used for environmental and bioterrorism sensing based on perceived risk and need.

The most common sensors are pressure (including flow rate and acoustical), temperature, radiation, chemical, and biological.

Sensors can be coupled together and transmit data via wireless networks to sites where the data is analyzed.

Disclaimer

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