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EDITORIAL—SPECIAL ISSUE

SCALABLE ENVIRONMENTAL MONITORING SYSTEMS: THE SPREAD OF TECHNOLOGIES TO COME

Human health and environmental risk assessments require information on the types, concentrations and distribution of contaminants in air, water, and land. Such information includes data that are usually acquired through carefully planned monitoring programs. Data acquisition, analysis, visualization, and interpretation are critical to environmental management programs in many countries. A prime example of the utility of system monitoring is the non-detection of the recent tsunami in the Indian Ocean which indirectly led to the deaths of more than 100,000 people. Although most environmental hazards do not generate such dramatic disasters, the design and implementation of monitoring systems can support both preventive and remedial approaches to environmental management, disaster mitigation, and public health management. In environmental systems, verification and validation of predictive models that describe both microscopic and macroscopic phenomena over large spatio-temporal scales require automatic sensing systems and data relay to processing and visualization points.

The hierarchy of monitoring technologies extends from low-technology monitoring wells to advanced satellite systems. At the basic level, the installation of groundwater monitoring wells, sediment sampling ports, radiation monitors, and air samplers around industrial and municipal facilities, as well as sensitive ecological systems, is necessary for early detection of hazards, tracking of contaminant release, fate and transport patterns, and verification of the effectiveness of remediation measures (regulations, incentives, clean-up, etc). The emergence of advanced monitoring systems that ride on recent developments in nanotechnology, power electronics and wireless communication systems has made it possible to implement integrated monitoring systems for continuous acquisition of environmental data. Essentially, technological “leap-frogging” from traditional

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technologies that are labor-intensive, cost ineffective, and inefficient, to lower-cost but high-technology systems is possible. This is comparable to the transition from non-existence of land telephone systems a few years ago, to the current ubiquity of wireless telephones, even in rural villages.

At the front end of research is contaminant sensing technology development in which various biological, chemical, and physical impulses are used to detect the presence and motion of contaminants. Among these techniques are motion sensing using waves, fluid dielectricity for contaminant concentration determination, and light scattering for dust density estimation. Although the reversibility of sensor condition after initial contact with contaminants is still a technical challenge that plagues the translation/matching of sensor impulses to incident contaminant concentrations, recent successes with fine-tuning of sensors to particular contaminant concentration ranges and mounting of several sensors that target a diversity of contaminants on a single sensor head are welcome advances. Miniaturization of sensors such that they can match the nano and micro-scale of physiological and ecological processes is also a target. Beyond sensing mechanics, the configuration of sensor networks over large regions in air, land, and sea and processing/management of large amounts of resulting data are significant challenges. Undoubtedly, the next two decades will usher in developments such as the use of vehicles, cell phones, roadway signs, and even personal clothing/shoes, as embedment objects for a variety of miniature sensors for environmental contaminants, and human and ecological response parameters. It is estimated that about 2.8 billion mobile telephones are currently in use with about 1.2 million telephones added each day. These telephones provide excellent opportunities for embedment and networking of environmental sensors. The installation and operation of sensor networks have already found application in some environmental hazard assessments. The U.S. National Oceanic and Atmospheric Administration (NOAA) operates six buoy-mounted pressure sensors in the Pacific Ocean. Other NOAA sensors that are anchored to the ocean floor as part of the Deep Ocean Assessment and Reporting of Tsunamis (DART) system have the capacity to detect tsunamis as low as 1 centimeter.

The Array for Real-time Geostrophic Oceanography (ARGO) comprises 3000 temperature and salinity sensors on as many floats that are globally distributed in the oceans. It can generate more than 10,000 temperature and salinity profiles monthly. Access to some environments for placement of sensors is constrained by high hazards. Besides, the distribution of expensive sensors over very large areas is not financially feasible. Consequently, the most practical large-scale environmental monitoring systems are those that are composed of in-situ sensors and satellite observation systems with data communication capacity. An example of such a system is the Global Observing System (GOS) operated by the World Meteorogical Organization (WMO). The European Union's Global Navigation Satellite System (GNSS) which has a maximum coordinate accuracy of 10-30 meters, is designed with capacity for detection of gas leaks from pipelines. Among other important environmental monitoring satellites are ENVISAT (European) for monitoring of lakes, snow cover, biomass, and gaseous pollutants; AQUA (US) for monitoring earth's radiation budget, ozone levels, aerosol concentrations, sea ice and sea surface temperature among other factors; and RADARSAT (Canada) for tracking ice and glaciers. Advances in integrated circuits, data storage and transfer capacity, robotics, sensor versatility, and data interpretation and visualization systems will greatly enhance the ability to monitor the environment at a wide range of spatio-temporal scales.

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