Environmental Monitoring Applications

Subjects: Remote Sensing

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Concerns about global environmental challenges, such as the alarming increase in pollution of oceans, waterways, land, and air, are becoming more and more prevalent in contemporary society. Environmental pollution has evolved into more than a health concern because of global industrialization and mass consumption patterns; it now represents a danger to whole ecosystems. It is critical to comprehend its causes and mitigation strategies. Adequate and timely environmental data are required for risk forecasting and early warning for environmental disasters.

Keywords: environmental monitoring ; optical waveguide ; optical fiber ; photonic sensors ; gas sensing ; water quality monitoring

1. Introduction

Environmental monitoring includes all procedures and actions taken to assess the state of the environment. The previous century has seen significant advancements in the field of environmental monitoring, but the on-site control of toxins remains a challenging issue. In particular, the requirement for effective early warning systems is expanding along with the number of polluting sources [1]. The management of environmental deterioration and the preservation of the natural environment's quality for the benefit of future generations depend on real-time and on-site pollution monitoring. The traditional analytical methods, which are based on chromatographic [2] and spectroscopic technologies [3], continue to be the most effective for controlling the environment because of their precision and sensitivity. Nevertheless, these procedures are restricted to centralized laboratories, call for pricey equipment, take a lot of time, and necessitate experienced workers. Optical sensors and photonic devices have recently come to light as intriguing alternatives to conventional analyses' exorbitant costs and slow speed. Due to their speed, specificity, sensitivity, reusability, ability to permit permanent and unattended operation in the field, and ability to provide the portable analytical instruments and early warning systems that are required [4].

Environmental risks pose a threat to both humans and the things we consider important. Even though they might have a variety of diverse sources, we typically conceive of dangers as arising from the interaction of human, technical, and natural systems. As a result, we frequently categorize hazards based on the events that cause them: rare natural occurrences (such as earthquakes and hurricanes) [5] and relatively common ones (such as blizzards and coastal erosion), extreme technological occurrences (such as nuclear power plant accidents or chemical spills), unrest and armed conflict, biological agents, or biohazards (epidemics, infestations, and bioterrorism), and chronic and globally significant hazards. Floods are the most frequent environmental hazard, damaging more than earthquakes, volcanic eruptions, and tsunamis combined [6]. Flooding may be an attribute of a complex of dangers during extreme weather events that also include mudslides, gales, and tidal surges and causes much more havoc. Floods are the worst form of danger since they often occur, have a wide-ranging impact on every region of the Earth, and are monster threats that do not simply happen once in a lifetime [7]. Low-magnitude, frequent floods can harm farmland, disrupt, or destroy buildings and infrastructure, stop business and other operations, expose people to health concerns, and so forth.

An appropriate supply of high-quality water is essential for health and is a fundamental human right. However, drinkable water is becoming extremely scarce [8]. In special, the health dangers caused by dirty water sources are more widespread and more harmful in poorer nations than in wealthy countries [9]. Surface water may be contaminated by sewage, industrial water discharge, or runoff from land clearing [10]. Ground water can also be poisoned by saltwater intrusion or waste dumping sites [11]. Water supplies were not always continuously assessed and investigated [12]. It takes sophisticated monitoring techniques to obtain evidence about pollutants in the environmental ground and surface water, safeguard water quality, and enhance the quality of household water supplies [13].

Due to recent developments in the creation of portable, less expensive air pollution sensors reporting data in near real time at a high time resolution, improved computational and visualization capabilities, and wireless

communication/infrastructure, the framework for air pollution monitoring is quickly changing. By strengthening compliance monitoring and complementing ambient air monitoring, these developments could assist conventional air quality monitoring. With the use of sensors, communities and individuals are starting to have the knowledge they need to understand their environmental exposures. With these data, community- and individual-based pollution reduction plans can be devised, and connections to health markers can be understood.

The evanescent wave sensors track variations in the refractive index [14][15][16][17]. To produce a propagating or localized electromagnetic mode, these sensors make use of the electromagnetic waves' confinement in a dielectric and/or metal structure [18]. A portion of the restricted light spreads to the surrounding medium, producing the evanescent wave. Through this evanescent wave, refractive index shifts in the external medium cause a local change in the excited electromagnetic mode's optical characteristics, most notably a variation in the effective refractive index [19]. When a receptor layer has been mounted on the surface of the guiding structure, the exposure of the functionalized surface to the complementary analyte and the ensuing (bio)chemical interaction between them causes a local change in the refractive index. The interaction may be quantified by correlating its amplitude with the concentration of the analyte and the interaction's affinity constant. Only changes near the sensor surface will be detected since the evanescent wave only approaches the exterior medium up to hundreds of nanometers and decays exponentially; as a result, the background from the external medium will be minimally affected. The ability to work under a label-free scheme gives evanescent wave sensors several benefits over other types of sensors, such as fluorescence sensors [20]. This results in a quicker and more affordable total detecting process. The scheme of the evanescent wave label-free sensing is shown in **Figure 1**. Labels may also have an impact on how the receptor and analyte interact, which may result in decreased performance when analyzing a complicated matrix. Other benefits of photonic sensors are their resilience to electromagnetic interferences, high sensitivity, wide bandwidth, and, most significantly, their potential to be made smaller and more portable thanks to the scalable technologies used in their production.

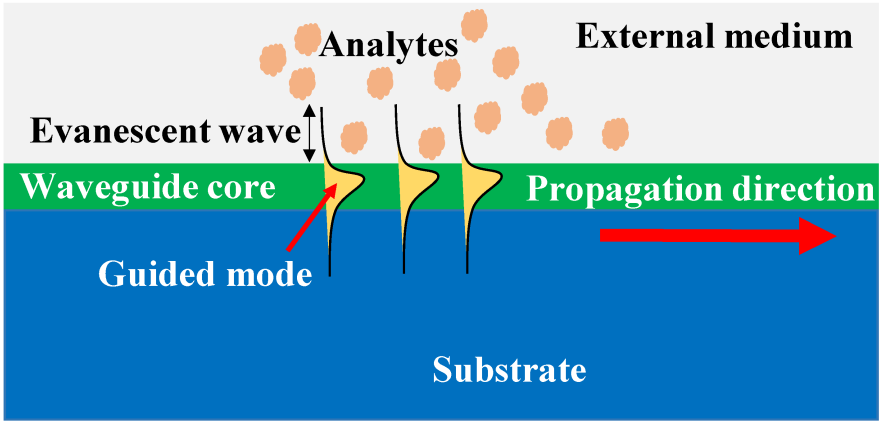

Figure 1. Illustration of evanescence field sensing.

2. Benefits of Environmental Monitoring

The goal and advantages of environmental monitoring are to determine if the environmental quality is improving or declining. Making choices for governmental and non-governmental organizations requires a lot of information, which is obtained by environmental consultants by monitoring the environment. Observing and analyzing trends and patterns in the presence of air pollutants in the atmosphere is the primary goal or advantage of environmental monitoring. The purpose of environmental monitoring varies depending on the circumstance, but it is crucial to ensure that businesses comply with environmental laws and regulations, assess the effectiveness of recently installed machinery, and monitor employees' health. It assists in identifying threats to people and wildlife, determining the potential for population movement from high-density to low-density regions, and limiting gas emissions. The following are a few of the benefits of environmental monitoring:

√- The people who treat patients and raise public knowledge of the condition and its management strategies are healthcare professionals. They are also worried about how a certain initiative may affect the environment, for example. high levels of noise, poor air quality, etc. They are also worried about the long-term and short-term impacts of pollution on the ecosystem and human health.

√- When engineers design the new seaside motorway, they should be aware of potential sea level rise, the degree of vibration at the ocean's bottom, and any other environmental elements that could have an impact on the strength of the bridge, so that they may take safety precautions when building a bridge.

√- It is crucial to disseminate precise information about the location, timing, and severity level when a tsunami or earthquake strikes in a certain region so that aid may be sent promptly to the designated time and location. The advantages of environmental monitoring also include the ability to anticipate and respond to such incidents.

√- Environmental monitoring data such as severe rainfall, cyclones, and tsunami may be used by farmers, foresters, hunters, and fishermen to plan their activities. The intensity of the natural danger can be reduced if they are warned. Additionally, farmers may learn about their soil's fertility so they can utilize the necessary fertilizers to increase production.

√- Big industries must be aware of the kinds of pollutants and quantities released from their facilities. They require environmental monitoring data and take environmental pollution reduction measures; hence, they should be included in benchmarks.

√- Data from population monitoring are used by the government to make community mobilization decisions. The government may opt to relocate some industrial districts to low-density regions if a specific city has a high population density and is experiencing issues with the availability of water, energy, and, most crucially, space and land. Additionally, the government builds new communities by utilizing the information gathered through environmental monitoring.

3. Environmental Monitoring Applications

Scientific research and environmental monitoring are closely intertwined. For instance, the government can intervene if the environmental monitoring program identifies a specific contaminant that has the potential to harm aquatic or terrestrial species. Additionally, it can spark an investigation into how that contaminant affects people, animals, or aquatic life so that remediation techniques might be developed. Environmental monitoring includes keeping an eye on the human population, as well as the air, water, soil, and land. Additionally, it aids in recognizing environmental stress, comprehending environmental trends, and assessing the success of initiatives and programs. The environmental monitoring applications are shown in **Figure 2**.

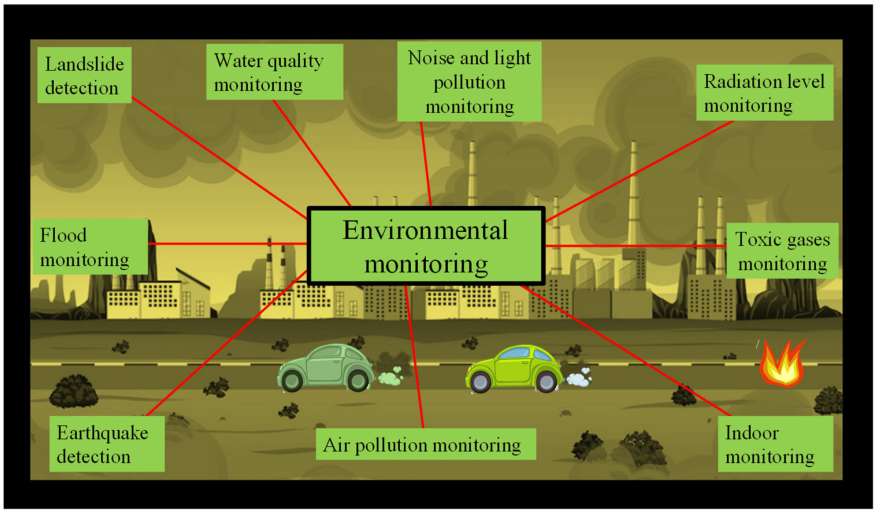

Figure 2. The environmental monitoring applications.

To manage resources such as oil, natural gas, arable land, and others economically, safely, and successfully, environmental monitoring is crucial. Various green technologies have been created to achieve this. Understanding and anticipating environmental changes, nevertheless, remain difficult tasks. As a result, it is important to keep an eye out for sudden changes that threaten the environment or public health [21]. Analyzing the chemical and physical characteristics of surroundings has been the focus of monitoring technology. As per analytes [22][23] or sensing principles [24][25][26], electrochemical sensors have been created as monitoring sensors in a variety of research. They benefit from low power consumption, good selectivity, and a linear connection between output signals and analyte content, among other things [27]. In most electrochemical sensors, the electrodes are covered in a catalyst that encourages the oxidation or conversion of particular chemical species [28][29]. The research of catalyst species with high durability in severe settings, even though they include such high-selectivity catalysts, proves difficult. As monitoring sensors in challenging situations, thermoelectric and electromechanical sensors, for example, have also been investigated.

The main environmental reason for death is air pollution [30]. The primary pollutants (nitrogen oxides (NO_x), ozone (O_3), volatile organic compounds (VOCs), and tiny particulate matter (SP)) emission levels are now steady in most major European cities, which is a troubling development. Reducing and tracking air pollution goes beyond only the effects on the environment and affects public health. Considering this sobering finding, it is essential to guarantee that the presence of these contaminants in ambient air is continuously measured to apply restoration measures and procedures for treating, destroying, or trapping discharge gases.

A microelectromechanical sensor has received a lot of attention due to its tiny size and affordable fabrication [31]. Due to failures brought on by corrosion, electrical disturbance, creep and plastic deformation, and hostile conditions, such sensors have a limited lifespan. It is essential to build sensors that are robust in tough settings for lengthy operating times, particularly since environmental monitoring sensors must function for extended periods in challenging situations. Systems of heuristic quality control will concentrate on effective behavior and environmental constraints on a continuous, real-time basis to identify potential failures at an early stage and create better a sensor platform that promotes better reliability tests and environmental monitoring methods. Due to their tiny size, low power consumption, and perhaps cheap manufacturing costs, wireless sensors—also known as “nodes” or “motes”—are appealing for this application [32]. Additionally, they are simple to question, and connection between units is employed to create a network that collects all the data necessary in real-time and either transmits it or, if attached to a memory, retains it for later use. Sensors can be interfaced with a variety of wired or wireless communications interfaces as necessary, based on the desired application [33][34].

Due to their compact size, versatility, and affordable production, microelectromechanical systems (MEMS) have the potential to significantly contribute to the shrinking of wireless sensor nodes. It may also be possible to create sensor redundancy because of the manufacture of numerous MEMS sensors on a single substrate, allowing for better degrees of integration and dependability. MEMS sensors offer several benefits, particularly in the context of Health and Usage Monitoring Microsystems [35]. The ability to correct cross-sensitivities and the potential for deploying the resulting chip in a larger modular system where sensed data can either be logged or immediately processed make MEMS-based sensor technology a rapidly expanding field with a promising future in a broad range of uses.

The usage of optical fiber sensing techniques has expanded over the past 30 years to a wide range of applications in several scientific fields. With the introduction of realistic, low-loss single-mode fiber created for the telecommunications sector in the middle to late 1980s, the technology, and its specialized instrumentation began to appear as a separate subject. This made it possible to communicate across great distances and to sense environmental variables. For hostile conditions, the optical fiber sensor is a feasible sensor that employs optical cables instead of electric wires because they have less heat loss and a higher data bandwidth than electrical sensors [36]. Extensive optical connections enable interconnection over distances of hundreds of thousands of kilometers. Submarine cables installed all over the world have enabled the connection of vast information technology resources from continent to continent. Because optical fiber has special properties including immunity to electromagnetic interferences and chemical corrosion as well as minimal heat loss, optical fiber cables guarantee durability even under the oceans for extended periods [37]. This shows that the optical fiber sensor can also produce and transmit measurement data with high sensitivity even under challenging environmental circumstances, as those seen in nuclear power plants [38][39] and downhole oil recovery wells [40]. Additionally, the optical fiber sensor is compliant with the latest fiber-optic communication infrastructure, allowing for remote management of environmental surveillance using a network operating system.

Electrochemical and optical sensors have seen rapid advancement in recent years [41][42]. Their usage is becoming simpler, and the range of potential uses is expanding, notably for measuring air quality. The development of sensing devices has altered how many different air contaminants are monitored, enabling quick online readings in dense networks. The cost of air quality measuring technology has decreased, making it more generally accessible. Although the usage of sensors is ubiquitous, it is difficult to determine the accuracy of the measurements, and because of the swift advancement of the technology, it is also difficult to predict long-term performance [43].

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