CHAPTER ONE

Introduction

In this introductory chapter we present an overview of subsurface sensing technologies and applications. We emphasize that subsurface sensing covers a wide range of disciplines, methods, and applications and present the main and auxiliary sensors commonly used in subsurface sensing. We emphasize the need for advanced signal and imaging techniques as well as sensor data fusion techniques. We also address a number of the barriers present in subsurface sensing and introduce common issues associated with the medium and certain properties of the soil and with temperature and humidity during data collection as they relate to the performance of sensing devices. We include both primary and secondary sources for subsurface sensing technologies and applications.

Subsurface detection and identification of buried geological and human-made structures currently represent an important research area and a progressive technological concept throughout the world. The scope of the problem is very complex and the basis of the topic depends on the wide area of demands: from military to commercial requirements, such as locating underground pipes, buried mines, and archeological or anthropological artifacts. The variety of unknown false and undesired targets under the ground complicates the object identification task. Moreover, the medium involved is usually lossy and inhomogeneous. The size, geometry, constitution (i.e., dielectric, metallic, explosive, etc.), and depth of the target object and the characteristics of the medium (i.e., wet soil, sand, etc.) are the principal parameters for detector designs. Unfortunately, there is not yet a single method or unique system that can manage to detect every type of object of any size, structure, depth, or soil. Therefore, a number of convenient sensor technologies must be considered regarding specific situations. These sensors may have common, similar, or different capabilities for the detection of desired targets.

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In this book we compile and present methods available to the growing number of potential users of subsurface sensing technologies, regardless of their educational or academic backgrounds, involved in physics, geophysics, civil engineering, archeology, or electrical engineering. A variety of sensor technologies and radar systems, based primarily on electromagnetic, acoustic, infrared, and chemical characteristics, are examined for their pros and cons as related to operating principles, strengths, limitations, and feasibilities. Furthermore, some convenient multisensor approaches to a wide range of applications are examined to reach the best detection performance in specific cases.

Subsurface sensing is a multidisciplinary research area combining expertise in wave physics, sensor engineering, image processing, and other areas, such as agricultural engineering and geophysics. It covers all areas of subsurface sensing technologies, such as radar, interferometer, ultrasonics, acoustics, microwaves, millimeter waves, submillimeter waves, infrared, and optics. Some examples of common applications are the detection, identification, and classification of objects, structures, and matter under and at surfaces, mapping pollution plumes underground, and nondestructive evaluation and testing of materials. Other sensing areas, such as seeing through walls, locating victims in buildings or rubble, personnel and vehicle surveillance, and intrusion detection and assessment are closely related and utilize similar sensing technology.

Detecting, locating, and identifying objects that are obscured beneath a covering medium all share the problem of distinguishing the effect of a dispersive, diffusive, and absorptive medium from the desired details of the subsurface structure and functionality. The problem is similar whether the wave probe is electromagnetic or acoustic, whether the medium is soil or concrete, or whether the target is a landmine or a pipeline. The properties of the medium are one of the leading items that determine the technology and technical specifications. For example, the effectiveness of inductive metal detectors to detect metal-cased antipersonnel mines is greatly reduced by metal clutter, such as metal fragments, spent ammunition, shrapnel, and cans in the soil. The presence of highly magnetic minerals may cause strong attenuation, which prevents the penetration of electromagnetic signals at certain frequency bands. Characterization of the medium, an important area for subsurface sensing, still constitutes a challenging task.

A second problem arises from varying properties of the medium. Subsurface inhomogeneities such as rocks, tree roots, and water packets are also a major concern and have the potential to cause false alarms. In such random inhomogeneous and highly cluttered environments, techniques to image objects quantitatively are limited. The use of a single sensor technology in such a complex environment is usually not reliable. Sensor or information fusion techniques are often used to overcome the shortcomings of available technologies. The fusion of more than one physical probe and the analysis of complementary information from multiple probes is an important avenue to progress in difficult subsurface sensing problems [1]. Combining different sensor inputs to optimize the information gathered is also a challenging area. Due to the lack of a theoretical basis, success in one problem is not easily applied to other domains. Therefore, sensor or information fusion is often applied on an ad hoc basis.

Ground-penetrating radar (GPR) is one of the best assessed and most recognized remote sensing tools. The use of GPR technology dates back to the late 1920s [2]. Advances in GPR data visualization and processing have increased its use significantly in a growing number of applications, from archeology to agriculture. In the 1990s it was particularly popular for use in the Humanitarian Demining Research and Development Program in the United States. This led to a marked increase in the number of GPR systems made available. GPR technology has reached a level of maturity but is still an active area of research, due to its limitations and varying effectiveness with the electrical properties of the medium. Imaging and visualization of GPR data sets are still one of the most active areas of research, as the raw GPR data are often difficult to discern and interpret. Advances in computer technology made it possible to process GPR data in real time. Today's GPR systems even allow for on-the-spot decision-making capabilities.

Metal detectors find numerous applications daily, such as screening people before allowing them access to airports, schools, and other critical buildings. They are also used as a primary sensor for many subsurface sensing applications. For example, in archeological explorations they are used to find metallic items of historical significance. In geological research they are used to detect metallic composition of soil or rock formations. Perhaps one of the most important applications for metal detectors is to locate mines or other explosive devices, such as unexploded ordnance. The main challenge for metal detectors in subsurface sensing applications is not just metallic debris in the areas surveyed; in addition to temperature and moisture conditions, the electromagnetic properties of soil also greatly influence the performance of metal detectors. It is for this reason that the electromagnetic parameters of the host medium are taken into account for object identification [3]. Inductive metal detectors are the type used most commonly when searching for antipersonnel landmines. Electromagnetic induction–based metal detectors are also popular for salinity monitoring of agricultural lands and soil water content measurements. Detecting all the subsurface characteristics of agricultural, archaeological, and other types of sites is not possible using a single remote-sensing instrument. This is also true for salinity monitoring. Metal detectors are thus used in combination with other sensors, such as GPR systems [4], as, once again, this requires advanced signal and sensor data fusion techniques to increase the effectiveness of subsurface instruments in varying soil conditions.

Tomographic imaging is a nondestructive technique used to detect critical deformities on roads, railways, highways, and bridge decks. There is also a huge interest in tomographic imaging methods to see through walls for military and security applications. Tomographic imaging techniques include optical tomography, electromagnetic tomography, electrical impedance tomography, and magnetic resonance electrical impedance tomography, to name a few. Tomographic imaging techniques have also been used to detect buried objects such as landmines. Some of these application areas are covered in Chapters 5 and 11.

Acoustic techniques are powerful tools for subsurface sensing, especially in the area of geological research, mainly because of the ability of acoustic signals to travel relatively long distances in a variety of rocks and sandstones, which in contrast to soils, show modest scattering and absorption [5]. In civil engineering, defects appearing in structures are determined by monitoring vibroacoustic signal parameters. In a recent study it was demonstrated that acoustic-to-seismic coupling was an effective and extremely accurate technique for the detection of buried landmines in soils [6]. There is growing interest in using acoustic methods for buried object detection and nondestructive testing of structures [7].

Sensor technologies using biological and chemical methods, nuclear quadrupole resonance, x-ray imaging, and infrared and hyperspectral systems are the auxiliary sensor types generally used in specific application areas or to improve primary detector performance. These sensors are discussed to some extent in Chapter 7. Other chapters are devoted to specific application areas in security, transportation, and civil engineering and agriculture.

RELEVANT RESOURCES

The latest research on subsurface sensing is distributed throughout journals and conference proceedings from various fields. One dedicated journal is *Subsurface Sensing Technologies and Applications*. As subsurface sensing is a multidisciplinary research area, relevant information is spread among a number of journals: *IEEE Transactions on Geoscience and Remote Sensing*, *IEEE Transactions on Microwave Theory and Techniques*, *IEEE Transactions on Magnetics*, *IEEE Transactions on Antennas Propagation*, *IEEE Instrumentation and Measurement Technology*, *IEEE Sensors Journal*, *Journal of Engineering and Environmental Geophysics*, *Journal of Applied Geophysics*, *Journal of Applied Physics*, *International Journal of Infrared and Millimeter Waves*, *Journal of the Optical Society of America*, *Journal of the Acoustical Society of America*, *Journal of Geophysical Research*, *Journal of Materials Chemistry*, *Biosensors & Bioelectronics*, *Soil Science Society of America Journal*, and *Remote Sensing of Environment*, to name a few. A journal with an information fusion emphasis is *Information Fusion*. The *International Journal of Approximate Reasoning*, *Fuzzy Sets and Systems*, and *Transactions on Neural Networks* are some other sources of information on sensor data fusion.

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