Joachim Ender, Moeness G. Amin,
Gianfranco Fornaro,
and Paul A. Rosen

Recent Advances in Radar Imaging

Radar imaging reaches back to the patent on synthetic aperture radar (SAR) by John Wiley in the year 1954. From the early days of SAR when imaging was performed using photographic film technology, to modern times where enormous images can be formed on a single computer in practically no time with exquisite accuracy and resolution, there have been tremendous advances in the field. These advances have been, to some degree, motivated by the increasing availability of high-quality SAR data from the ever-expanding fleet of international airborne and spaceborne SAR systems in both the civilian and military sector. In the civilian sector alone, the National Aeronautics and Space Administration's (NASA's) SEASAT in 1978, followed by the NASA shuttle imaging radars SIR-A, SIR-B, and SIR-C, initiated a remarkable development of international radar missions including Canada's RADARSAT mission, Japan's Earth Resources Satellite (JERS) and Advanced Land Observing Satellite (ALOS) missions, Europe's European Remote Sensing (ERS) and Environmental Satellite (ENVISAT), and NASA's Shuttle Radar Topography mission (SRTM), as well as Germany's TerraSAR-X satellite. These, in turn, have led to a new generation of missions with even greater sophistication in modes and operational characteristics. Airborne SAR test beds that offer even greater resolution and mode diversity often support the satellite programs. The multidecade time series of data these missions provide have inspired researchers to develop exciting new processing technologies for exploitation, which continue to evolve.

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SAR systems are now capable of providing resolutions comparable to optical systems while operating in all weather and times, which are features of key importance for many applications. SAR data provide key information about the imaged area, unique and distinct from what optical systems can provide in that the SAR is sensitive to the electrical and roughness characteristics of the scene rather than its chemical properties. The ability to control the illumination source gives a range of diversity in observations—polarization, phase-time, and frequency dependence—enabling broad applications including classification and change detection, forestry, soil characterization, monitoring of areas subject to natural and anthropogenic hazard, and many others.

Air- and space-based sensors that have been realized span frequencies extending from very high frequency to the upper millimeter wave region, offering deep exploration of scattering phenomenology and insights into the nature of targets and surfaces. Extended SAR capabilities, such as the Shuttle Radar Topographic mission cross-track interferometer, the TanDEM-X satellite pair and the Constellation of Small Satellites for the Mediterranean Basin Observation (COSMO)/SKYMED constellation, have expanded applications of SAR in unique and important ways, including across/along track and repeat pass interferometry techniques for topographic mapping, velocity estimation of moving targets, and accurate deformation monitoring, as well as multiband operations and polarimetric exploitation: options that add to the almost incredible improvements in geolocating fine-resolution images through precision data processing. Today's SAR technology offers a cost-effective alternative to traditional techniques, capable of reaching accuracy and measurement density that are starting to be comparable to lidar systems while retaining synoptic view and global coverage advantages.

This special issue of *IEEE Signal Processing Magazine* (*SPM*) provides an overview of recent developments in SAR imaging and delineates potential research avenues for further progress in this area. It covers the relevant topics of high-resolution and multistatic SAR imaging, SAR imaging of complex scenarios and buried targets, SAR interferometry, SAR tomography and polarimetric SAR, and multipath mitigation and exploitation in SAR. The intent is to provide readers with a breadth of topics in the theory and applications of SAR processing, capturing recent developments and highlighting new frontiers.

The first article by Ash et al. addresses the issue of overcoming limitations of traditional SAR imaging based on narrowband/narrow angle acquisition. It provides an overview of the methods used for wide-angle SAR imaging and deals with problems related to anisotropic scattering and the deviation from point scattering assumptions and their effects on data interpretation and processing.

Çetin et al. provide an overview of recent research on SAR imaging for increased resolvability of point scatterers, reduced speckle, proper segmentation, and robustness to limitations in data quality and quantity.

The article by Fornaro et al. focuses on the developments of SAR interferometry, which has enabled the monitoring of ground deformations with applications to natural hazards as in revealing seismic and volcanic risks and landslides and underground excavation/withdrawal. It also addresses the developments of SAR tomography that turns interferometric into multidimensional (space–time) imaging methods.

(continued on page 158)

low level of defocus, say about ±0.25 of a diopter and allowing for longitudinal vibrations of a similar order can result in a threefold increase in the eye's visual Strehl ratio—a popular metric of retinal image quality [16]. Such levels of defocus are typically encountered in emmetropic subjects (i.e., those exhibiting good vision without any corrective implements). Figure 2 depicts the concept of improving integrated image quality with longitudinal vibrations, provided that the retinal image plane is not at the focal point. Whether the temporal summation of longitudinal vibrations truly occurs in the human eye is yet to be proved. For this, wavefront sensors equipped with high speed (exceeding the Nyquist frequency of 120 Hz) and sensitive enough cameras need to be employed.

The optical system of the human eye presents challenges for future generations of signal processing professionals. Current approaches to study its dynamics are often reduced to an application of the off-the-shelf signal processing tools to a limited aspect of the system. However, a more comprehensive approach that integrates all available information in some form of data fusion is needed to fully understand all its intricacies. Gaining such knowledge would benefit not only the visual optic community but also those interested in computer and machine vision.

AUTHOR

D. Robert Iskander (robert.iskander@pwr.edu.pl) is a professor of biomedical signal processing at the Institute of Biomedical Engineering and Instrumentation, Wroclaw University of Technology, Poland.

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(continued from page 15)

Zhu and Bamler provide a further insight into SAR tomography, and their article demonstrates the ability of compressive sensing to achieve vertical superresolution with data acquired by SAR systems operating in very high horizontal resolutions modes.

Still in the context of SAR interferometry, the article by Baselice et al. investigates methods based on the use of contextual information and addresses statistical methods to solve the multichannel interferometric SAR phase unwrapping problem for digital elevation model generation.

The article by Deledalle et al. covers the methods of filtering multichannel SAR data, represented by interferometric, polarimetric, or interferometric/polarimetric, to provide preservation of texture and structures.

SAR polarimetry, the topic of the article by Chen et al., provides insights in polarimetric target decomposition techniques for the interpretation of scattering mechanisms, including extension and fusion with interferometry.

Solimene et al.'s contribution deals with a unified treatment from the mathematical viewpoint of SAR imaging algorithms and discusses their generalizations to handle unconventional scenarios, such as through-wall imaging, imaging of urban canyons, and underground tunnel detection.

A further contribution to the imaging of buried targets is provided by the article by Kedzierawski et al., which addresses the topic of airborne ground penetrating radar (GPR), a combination of SAR and GPR, based on the use of time-reversal data processing algorithms.

Finally, Leigsnering et al. deal with the problem of scatterings and multipath when using SAR for imaging of building interiors. The article discusses both multipath mitigation and exploitation techniques and shows how to perform the latter with compressed observations.

We would like to express our deep gratitude to the many individuals who made this special issue of *SPM* possible. We thank all authors who submitted proposals and all reviewers whose recommendations significantly helped in improving the selected articles. We are also grateful to Abdelhak Zoubir, *SPM*'s editor-in-chief, and we are indebted to Fulvio Gini, special issues area editor, for his constant support and guidance throughout the solicitation and reviewing process, as well as to Rebecca Wollman for her valuable administrative assistance.

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