Very High-Resolution Remote Sensing: Challenges and Opportunities

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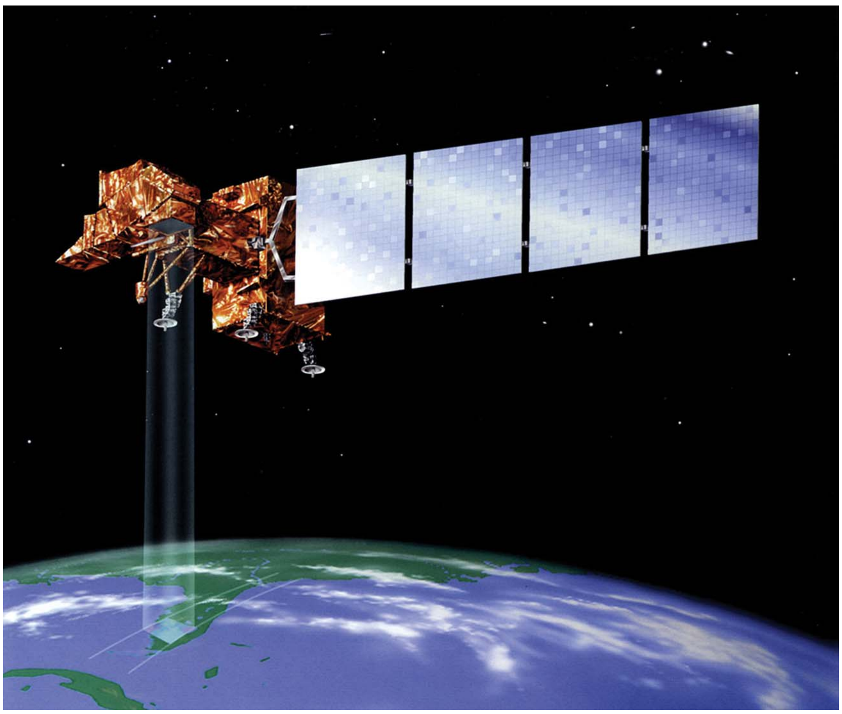

Landsat imagery courtesy of NASA Goddard Space Flight Center and U.S. Geological Survey.

I. RESOLUTIONS'S REVOLUTION

Satellite and airborne remote sensing is currently undergoing a technical revolution with the appearance and blooming development of very high-resolution sensors. This revolution concerns optical remote sensing as well as radar remote sensing. For high-resolution remote sensing sensors, *resolution* can have the following three meanings.

- *Spatial resolution:* Metric and submetric resolutions are currently available for satellite remote sensing. That opens the door for very accurate geometrical analysis of objects present in scenes of study. Meeting the corresponding opportunities and actually analyzing the images at the provided level of details and accuracy raises new challenges. For any given application, while more relevant information is available, it also comes with an increased amount of nonrelevant (to the considered application) details.
- *Spectral resolution:* After decades of use of *multispectral* remote sensing, most of the major space agencies now have new programs to launch *hyperspectral* sensors, recording the reflectance information of each point on the ground in hundreds of narrow and contiguous spectral bands.

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The spectral information is instrumental for the accurate analysis of the physical component present in one scene.

- *Temporal resolution:* Due to the launch of constellations of satellites and the increasing number of operating systems, the temporal resolution between two acquisitions over a given scene of interest has dramatically decreased. This opens the door to the accurate monitoring of abrupt changes and to efficient response in case of major disasters. Temporal phenomena with longer scales can also be monitored.

II. OPPORTUNITIES FOR A HIGH SOCIETAL IMPACT

The need for very high-resolution remote sensing data has grown in parallel to this technical revolution. As a matter of fact, a lot of applications, with an increasing societal impact, can now potentially be addressed using remote sensing. The most important and challenging applications are in the following fields.

- *Energy:* Biomass energy and forest inventory, optimal solar photovoltaic installations, snow cover monitoring for the prediction of hydroelectric energy product on. All these applications require remote sensing observations, with both a wide spatial coverage and a fine spatial resolution, very often together with a high temporal resolution.
- *Water:* Prevention and management of draughts, floods, monitoring of water quality, understanding of the oceanic circulation at mesoscales and smaller scales, observations of the temporal and spatial variations in water volumes stored in rivers, lakes, and wetlands in order to fulfill our basic need for fresh water. Again, all these applications require remote sensing observations.
- *Environment:* Detection of pollution, measurement of climate change, monitoring of urban growth and management of urban planning, data assimilation with large-scale models. Again, remote sensing is a premium tool.

III. INDUCED CHALLENGES

However, in order to fully exploit all the potential offered by the new generations of remote sensing sensors and to actually face all the applications with a very high societal impact, the following induced challenges must be tackled.

- *High performance computing*: The very high dimension of the acquired data and the increasing complexity of the processing algorithms require the design of adequate algorithms and architectures. With that respect, the use of graphical processor units (GPUs) generates a lot of research activities.
- *Understanding the physics and modeling*: This is a key issue in order to design optimal algorithms. With very high resolutions, one needs an in-depth understanding of the involved physics, e.g., for the interaction of the electromagnetic wave with the ground or through the atmosphere and the physics of the sensors for an accurate calibration. This knowledge should then be incorporated in the models: for instance, the statistical models traditionally used with average resolution synthetic aperture radar (SAR) data do not hold any longer. In the frame of hyperspectral data analysis, the current trend is toward the use of nonlinear mixture models, while linear models have been extensively studied in the past decade.
- *Signal and image processing*: Most of the traditional processing algorithms fail when the resolution increases significantly. For instance, conventional statistical learning becomes intractable with hyperspectral data because of the dimensionality of the data. Similarly, while it has been easy to classify urban versus nonurban areas with medium resolution data, very high-resolution data enable the accurate classification at the building scale, but the use of such data requires to completely redesign the whole processing chain.

IV. SPOTLIGHT ON HYPERSPECTRAL REMOTE SENSING

Interest in hyperspectral sensing has increased dramatically over the past decade, as evidenced by advances in sensing technology (currently operating American Hyperion EO-l and HiCo, European CHRIS PROBA, Indian HySi, or Chinese HJ-IA, and planning for future hyperspectral missions, such as Italian PRISMA, German EnMap, Japanese HISUI-ALOS-3, French Hypxim, or American HyspIRI). These are the bricks toward a virtual constellation of hyperspectral sensors. The latest trend consists in further exploring the electromagnetic spectrum toward thermal bands. The increased availability of hyperspectral data from airborne and aforementioned space-based platforms and development of methods for analyzing data and new applications led to the launch in 2009 of a series of annual specialized workshops on hyperspectral sensing that had technical sponsorship of the IEEE Geoscience and Remote Sensing Society.

The key issues specifically related to the analysis and processing of hyperspectral data are as follows.

- Data simulation and modeling, requiring a good understanding of the physics data compression.

- Calibration and atmospheric corrections.
- Band selection, feature extraction, and subspace identification: While the acquired data are highly dimensional, several hundreds of spectral bands are typically acquired, and the intrinsic dimension of the data is significantly smaller. Reducing the dimension of the data to the optimal dimension with respect to the needs of the applications or the actual data remains a very active field of research.
- Target and anomaly detection: Most often related to critical defense and security issues, target and anomaly detection is a very important topic to which hyperspectral imagery can significantly contribute.
- Mixture analysis, end-member extraction, and spectral unmixing: A given pixel frequently represents several different materials which are contained within the resolution cell. As a consequence, the observed spectrum is a mixture of the spectra of these elements. Analyzing these mixtures, determining the corresponding end-members and the associated abundances, and ultimately unmixing the data are also key issues in hyperspectral remote sensing.
- Classification: Within the hyperspectral processing chain, classification is probably the topic that has garnered the attention of most researchers and resulted in the largest number of published papers. Be they unsupervised (clustering) or supervised (algorithms based on training and machine learning), most of the published methods are explicitly or implicitly based on statistical modeling of the spectral characteristics of the classes.
- Noise estimation and removal: Hyperspectral data are corrupted by wavelength-dependent and sensor-specific noise, which significantly impacts data and resulting data products. Modeling this noise and removing it via appropriate filters are also important topics related to hyperspectral sensing.

V. SPOTLIGHT ON RADAR REMOTE SENSING

At the longer wavelength of the electromagnetic (EM) spectrum, SAR has become very effective in many Earth observation applications, especially in view of gradually increasing cloud cover, probably due to global warming. The spatial resolution of most civilian SAR systems has been limited in the past mainly because of political reasons. However, there have recently been a large number of SAR systems launched into Earth orbits with a greatly increased spatial resolution. In certain applications, however, high spatial resolution is not necessarily advantageous, and new research is essential for this type of applications. Newly available, fully polarimetric SAR systems, i.e., systems that emit a mixture of polarizations and use receiving antennas with a specific polarization to collect several images, including the Japanese Aerospace Exploration Agency (JAXA) Advanced Land Observation Systems (ALOS) PALSAR, the German Aerospace Center (DLR) TerraSAR-X, and the Canadian Space Agency (CSA) RADARSAT-2, now routinely provide us with fully polarimetric data with varying spatial resolutions, and comprehensive research to study the effects of spatially very high resolution on various applications is now becoming urgently needed. In the SAR and polarimetric SAR applications, another important resolution to consider is with respect to the interferometric SAR (InSAR), based on using measurements from two differently positioned radars, and differential interferometric SAR (D-InSAR) applications in both cross-track and along-track configuration geometry, ranging from static deformation of surface targets to moving target tracking.

In the classical EM spectrum, the microwave region is well separated from the visible and IR regions, and the realistic Earth observation window with SAR and now fully polarimetric SAR ranges mostly from the X-band (8–12 GHz) to the P-band (12–18 GHz). Until now, most space-borne SAR systems have operated in one frequency. However, different space-borne SAR systems such as ALOS, TerraSAR-X, and RADARSAT-2 make it now possible to use information from up to three frequencies almost in real time. In the microwave region, the spectral resolution cannot be as closely resolved as in optical region, but the scattering processes of the backscattering from targets make it possible to finely separate the target characteristics. Most Earth orbiting SAR systems will soon form a type of constellations, starting with Cosmo-Skymed, and followed by ALOS 1 and 2, and RADARSAT constellations. The constellation will greatly increase the temporal resolution in almost all aspects of SAR and polarimetric SAR applications.

VI. MORE DIVERSITY, FOR MORE OPPORTUNITIES... AND MORE CHALLENGES...

Additional topics of future promising developments include the use of multiangular data now available thanks to the increased agility of the satellite. The IEEE Geoscience and Remote Sensing Data Fusion Technical Committee recently held a scientific challenge to demonstrate or simply discover and invent the potential of such data.

As a side effect of the increase of the number of sensors in operation, multimodal data, i.e., data acquired on the same scene by different sensors, are becoming more and more available. Taking advantage of this diversity is a key challenge as the data, such as optical and radar, respectively, have dramatically different characteristics and geometries, but—no thorn comes without a rose—they also do offer complementary information about the image scenes.

VII. CONCLUSION

As a conclusion, one could summarize the coming challenges as follows. Advanced information processing and architectures will be needed to bridge the gap between the potential offered by the new generations of sensors and the needs of the end-users to actually face tomorrow's challenges in many applications with a very high societal impact. As remote sensing researchers and engineers, this is our passion, our charge, and our responsibility. ■