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**Special Section Guest Editorial:
Advances in Infrared Remote
Sensing and Instrumentation**

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The term “remote sensing” has traditionally been applied to peaceful applications of space-based observations. The word “remote” could also imply noncontact and nondestructive, or noninterfering (sensing), especially when describing sensors. If you actually analyze the operation of the optical instruments, you realize that most of them function as “remote” in the sense that they do not interfere with the naturally occurring processes and the information is carried imperceptibly by electromagnetic radiation.

Most optical instruments perform initially similar functions in the laboratory setting. Consequently, they are incorporated as remote sensing subsystems. In remote sensing satellites, they are coupled with a telescope whose function is to collect as much radiation as possible and bring it into the instrument to extract specific spatial, temporal, or spectral information about a distant object. In this sense, most remote sensing instruments are used for Earth remote sensing and in astronomical observations. The significant difference is that in the first case, the telescope or camera looks at the scene below, while in the second case, it looks at the space above or sideways. This is particularly useful in the case of IR astronomy.

Among the original remote sensing satellites launched in space in the 1970s, we could include imagers on the appropriately chosen orbits to provide as uniform and efficient coverage over the area of interest as feasible. The orbit design and the instantaneous field of view of the moving instrument are two critical additional parameters that contribute to making a traditional, Earth-based instrument a remote-sensing one. The movement of the instrument-carrying vehicle, be it a satellite, a plane, or a rocket, opened the possibilities for multispectral imaging, using initially just a few bands with beam splitters and filters, incorporating several separate channels, each with its own detector assembly.

The 1980s brought significant technological developments. Detectors replaced film as the recording medium with the advent of widely available CCD (charge-coupled device) technology in the visible, and line and staring arrays in the IR. The capability of detecting large amounts of multispectral data paved the way for on-board spectroscopy, Fourier transform interferometry, multi- and hyper-spectral imaging, in addition to imaging and radiometry where the total amount of radiation is collected within a spectral band measured. All of these instruments are represented in the current special section, reflecting the continuing evolution of the instrumentation arising from improvements in diverse areas of technology. As the Earth surface and the space environment around it are believed to be changing, it has become of highest importance to monitor them. Scientists and engineers are developing modeling algorithms potentially to predict future, both on a short and long time scale. Some time scales are as long as decades (carbon dioxide distribution). Humans and improvements they make to their habitat also result in slow environmental changes.

Remote sensing monitoring envisions a number of platforms from which to make observations, including satellites, space stations, and even the moon, or an orbiter circling a nearby planet such as Mars. Most of the time, we are interested in a planet in our own solar system; other times we want to examine an asteroid that ventured inside it. Does it have water or some precursors of life? Occasionally, we perform investigations outside our solar system, and fix our gaze into the cosmos to look at the distant stars searching for another Earth-like planet—to one day boldly go where no one has gone before.

Just like NASA, the ESA (European Space Agency) is also launching satellites to monitor climate and weather patterns. At the time of this writing, their scientists and engineers are performing the last-minute tests in support of the Seas and Land Surface Radiometer, planned for a

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2015 launch. It forms a part of the Copernicus program. Coppo et al. describe an instrument that represents an improvement over those launched previously, incorporating more visible through thermal-infrared channels. One of the new channels is dedicated to aerosol measurements and two other ones to fire detection. Of particular importance is the implementation of spatial imaging architecture to look at each Earth surface element from two angles, each with its own path through the atmosphere. The high-precision instruments incorporate continuous on-board calibration, with a look at a blackbody simulator every 0.6 seconds. Smith et al. describe the calibration procedure for this instrument in the companion paper.

In addition to making the sky blue and the sun yellow, providing fauna with oxygen and flora with carbon dioxide, the atmosphere is a gaseous enclosure around the Earth. It helps to keep the Earth surface temperature “just right” for its fragile inhabitants, not too cold and not too warm. With the flourishing of the Industrial Revolution, its by products started having an impact on our environment, although it took us about a hundred years to start monitoring these effects. Humanity is concerned about energy balance: the radiation flux at the top of the atmosphere is compared with that at the surface of the Earth. A difference between these two quantities requires an explanation so we may rest assured that the atmospheric constituents and forests are processing its radiative load in a sustainable manner. The Cloud and Earth Radiant Energy System (CERES) was designed to do just that. It incorporates a scanning radiometer that scans from one limb to the other. Smith et al. describe the point response function of the CERES instrument, its measurements, and its validation in the space environment. Identification of a small anomaly in the instrument field-of-view allowed the scientists to develop algorithms to compensate for its deleterious effects and still extract meaningful results.

Monitoring of the overall status of the Earth and its health was among the initial objectives of the remote sensing efforts. This included assessment of the distribution of water, ice, and forest covers, and conversely, possible propagation of dry regions and destruction of green cover. The very next ambitious space projects included monitoring the atmosphere, its water content, air flow, and distribution and movement of gases. Weather prediction was the original objective of the atmospheric infrared sounder on the Aqua spacecraft of the Earth observing systems. Currently, Pagano et al. are using this instrument to correlate the response of the distribution of carbon dioxide in the mid-troposphere with the vegetation growth in the northern latitudes.

A large number of instruments, though by no means all, used in remote sensing have successfully been deployed in laboratories before they were adapted for semiautonomous and remote-control, space operations. The atmospheric infrared sounder incorporates a complex focal plane layout, requiring equally sophisticated algorithms to determine at the same time the emissivity and temperature of the surface boundary layer, often in presence of clouds. One of the enormous challenges of deploying a multispectral / hyperspectral instrument is rapid and efficient data processing in a general format to deliver to multiple and simultaneous data users. Susskind, Blaisdell, and Iredell describe the version 6th products, with suitably formatted data to be available nearly in real time. The authors have performed error assessment. They ascertain that the auxiliary data obtained with microwave sounding unit may soon not be needed.

The Extreme Universe Space Observatory is an astronomical telescope that will be hosted by the Japanese Experiment Module on the International Space Station. For its proper functioning, it requires knowledge of temperature of the cloud top. This is usually accomplished with an IR camera with dedicated algorithms to determine cloud height and the temperature atop, often employing data from just two adjacent spectral bands. Adams et al. describe the design and algorithms residing on an IR camera, incorporating split window algorithms to determine brightness temperature and deduce real temperature from it. The algorithms are validated using the MODIS data within the same spectral bands, at 10.8 μm and 12 μm .

Just above the top of the atmosphere, which is really not a hard limit but rather a smooth transition region to ever more rarefied gases, there is the vast region of “space.” The absence of gases makes it favorable for the satellite orbits, as there is no air to slow down the satellite and to decrease its orbit height. Over 3000 known registered satellites and payloads occupy this near-Earth space. There, we find an increasingly larger number of debris objects: any human-made object in space that is no longer serving a useful purpose. Every space launch, whether successful

at lifting its payload into orbit or not, contributes throwaway components that freely float in space in addition to the useful payload.

The encounter of a functioning space vehicle with a debris object may prove catastrophic, so studies are being performed for debris localization, employing the IR technology. Space debris is estimated as having temperature anywhere from 100 K to 400 K, so the IR spectral region is most appropriate for its detection. McCall and collaborators propose that solar occultation techniques be employed to detect changes in temperature when the equilibrium conditions no longer apply. They classify space objects by their tumbling behavior and by a material-specific, temperature dependent parameter, absorptivity over emissivity ratio. The absorptivity refers to the total quantity over the solar spectrum, while emissivity is heavily weighted around the peak emission of the debris object. This quantity basically measures how rapidly the object responds to the step input during onset / offset of the solar heat load.

Planet Mars has held the interest of the solar system exploration community ever since humanity imagined that irrigation canals covered it, fueling the popular imagination that conditions exist there for human settlement. First, we sent satellites on fly-by missions, then imaging orbiters for systematic surveying, and finally we landed a roving vehicle with prospects for returning soil and rock samples. Even with a robot arm for excavation, only most primitive forms of life might be encountered. The next step in looking for evidence of life is to perform a detailed analysis of the atmosphere, its trace elements, aerosols, and winds. The European Space Agency is designing the ExoMars trace gas orbiter. One of the on-board instruments is a suite of three infrared spectrometers to quantify the gases in the Martian atmosphere. Korablev et al. describe preliminary design of three spectrometers, operating in near IR [0.73–1.6 μm], middle IR [2.3–4.3 μm], and thermal IR [4–17 μm].

Within the last twenty years, the development of high-resolution megapixel arrays in IR has ushered in the era of hyperspectral imagers in IR. They may function in conjunction with a spectrometer that disperses radiation spectrally along one spatial dimension of the detector array and performs line imaging along the satellite track direction. As the vehicle follows its trajectory along its orbit, line images are acquired sequentially. The enormous amount of data collected this way forms a so-called data cube, with two dimensions corresponding to the spatial imaging and the third one to the imaging within narrow spectral bands. Ting et al. describe the development of a two-dimensional GaAs/AlGaAs-based quantum well IR photo-detector array in support of such hyper-spectral imagers. Their work is particularly interesting as they essentially fabricate two detectors side-by-side, sensitive in the relatively broad spectral intervals [8–10 μm] and [10–12 μm]. Their focal plane arrays will be integrated with the hyper-spectral thermal emission spectrometers onboard future monitoring missions.

The lower wavelength limit of the IR region is well defined, as it is specified by the onset of the human visual response curve. Even radiometric concepts are modified, when they apply to the quantities within the visual range to correspond to the intricate responsivity of the human eye. The situation is quite different at the upper spectral limit of IR where the same classes of materials are used. Incorporation of antenna structures is often used to enhance the detector array performance, well into the terahertz spectral range. Tu et al. describe the advances of the micro-bolometer technology with enhanced sensitivity. They incorporate novel material, Nb_5N_6 (niobium nitrate), in a form of a thin film connected in series of three to increase sensitivity by about the same factor. They additionally increase the amount of collected radiation by employing a lens that focuses the radiation on the responsive surface. Both of these enhancements result in significant sensitivity improvement, making this a powerful bolometer architecture and promising sensor material.

One of the finest devices in the near IR region is an avalanche photodiode, developed originally to replace the photomultiplier tube for optical communications. It has low dark current, rapid response, and includes gain. The increasing complexity of the multilayer devices requires incorporation of about ten layers, each having approximately 100 nm thickness. Thus, the device fabrication and then testing is often being replaced by modeling in hope of cutting cost with simulation capabilities. Currently, several commercially available software packages exist to achieve this objective. Even so, the fabrication intricacies are still not adequately well modeled, at least not for the InGaAs/InAlAs avalanche photodiodes. Czuba, Jurenczyk, and Kaniewski describe discrepancies between predicted and measured behavior of these devices. They find that

the simulation models are mutually consistent but that differences exist between the predicted behavior and the measured properties. They propose that additional optical phenomena might be taking place in the actual device that have not yet been implemented into software simulation. They believe that it is very likely related to the interference effects.

Probably the most challenging mission that may be undertaken in the autonomous space exploration is a sample return mission; in comparison to a fly-by or an orbiting mission. It requires the additional step of returning the probe vehicle to its origin, bringing back some robotically mined samples. When such a mission is directed onto a small asteroid, all the challenges are intensified due to its limited spatial extent, overall mass limitations, need for real-time imaging, and lack of *a priori* knowledge of surface features and conditions. JAXA/ISAS (Japan Aerospace Exploration Agency/Institute of Space and Astronautical Science) developed a thermal-infrared imager system for HAYABUSA2. It consists of a thermal-infrared imager and a digital electronics. The system is due to be launched in 2014, aiming at retrieving materials and bringing them back to the Earth from the C-type (enriched in carbon) near-Earth asteroid 1999JU3, believed to contain organic matter and/or hydrated materials. Hihara et al. report on the SpaceWire-based thermal infrared imager system for asteroid sample return mission HAYABUSA2. The thermal IR imager incorporates an uncooled bolometer array with 320×240 pixels and employs efficient electronics for on-board processing, due to limited data storage and time consuming information transmission cycle. At the time of this writing, it is being readied for launch.

The extra-solar detection community is searching for new technologies and advanced instruments to enhance the possibility of detecting a minuscule, faint planet next to a large, bright star. The challenges in the development of suitable instrumentation are exacerbated due to the optical noise caused by the scattering and reflection throughout the volume occupied by the imaging components. Ferrari et al. are proposing a compact, single element, nulling interferometer for extrasolar planet detection. They report on the laboratory results demonstrating their novel planet detection technique. Strojnik and Scholl perform a trade-off study analysis for the optimal placement of the planet observatory. They compare the Earth, the space station, and the moon as potential sites. In a companion paper, Strojnik evaluates analytically the feasibility of deploying (multiple) Bracewell configurations to accomplish planet detection using optical means.

During the early stages of knowledge acquisition through remote sensing technology, it was applied to remote, inaccessible, and possibly even hostile environments. The surface of the ocean comes to mind, pristine regions of the Amazon rain forests, and Death Valley in California and Nevada. We only seldom think about how our presence in our own habitat, and our own modifications to it, including our constructions, influence our environment. The environment that we modify in turn significantly impacts our living conditions. Comparison of thermal characteristics of low-bush coverage of a patch of Earth surface with those of human-made structures (roofs, streets, parking lots, stadiums, etc.), we realize that artificial constructions tend to absorb and accumulate heat. Therefore, a city will generally be hotter than the surrounding cultivated land or natural landscape. Humans are, on the average, about 150- to 160-cm tall, so this distance is incorporated as a significant derived feature in human constructions. Luo and Li use LANDSAT data to determine the optimal size of the aggregates in spatial scales from 30 m to 1200 m. They identify heat islands primarily within the populated areas. Furthermore, they find that adjacent large rivers ameliorate the effects of high population concentration.

Li et al. examine in detail the relationship between the land surface temperature (in remote sensing sense) and population density, using LANDSAT-5 images from 2000 and 2009, for the area of Wuhan, China. They study both the population and population density effects. They find positive correlation between land surface temperature and these population parameters. They believe that these results should be an important input to the urban planners. The amount of contiguous residential and industrial area is to be decreased to control creation of the local heat islands. In the particular case under study, the city expansion encroached on the cooler, low heat-retention, arable lands.

The very last step in remote sensing to determine the overall health status of the planet Earth globally is actually data processing. This, by itself, is a vast field as it may be applied to any image acquisition system associated with an instrument or optical system. Xu, Zhang, and Duan propose a new algorithm employing unsupervised classification of the farmland upon image

segmentation. Texture signatures are constructed after texture gradient has been determined. They find high true-positive rates upon application of their algorithm. Interestingly, the raw data for this research was actually acquired with synthetic aperture radar, but it may easily be applied to infrared imagery.

Built-in areas are not the only human-made changes to the temperature distribution on the Earth surface. Environmentalists have expressed concerns about landfills for many years. They invariably are located outside the city limits when such area is initially allocated for the waste disposal. In time, they are filled and dirt is placed on top of them. Often, parks are erected due to their low gravitational load, permitting gradual settlement of grounds. Sometimes residential areas are built at or around former landfills as city sprawl accommodates the housing needs of young families. Thus, the landfills must be monitored for their emission of gases. Merla et al. propose that waste-disposal sites and landfills could be monitored in IR for differential temperature increase from a low flying aircraft so that spatial resolution may be high even with off-the-shelf devices. Then, any emission anomalies could easily be identified and their source located. With more knowledge about the hazards of modern living, humanity is well advised to implement strategies of monitoring decomposition and its side products. This is another area where the city managers will find IR technology ready to be implemented.

In our everyday activities, we are accustomed that vision is performed during daytime, in the so-called visible portion of the electromagnetic spectrum. We are learning to enjoy the benefits of having cameras in our private and public transportation, particularly convenient when using a vehicle in reverse gear. The possibility of expanding machine vision into IR for routine applications became available recently for night operations. We are taking advantage of the IR spectral interval with the arrival of the room-temperature two-dimensional IR detectors. We may now employ IR cameras to monitor transport infrastructures, such as bridges, either in stand-alone or in connected configuration. Dumoulin and Boucher evaluate the feasibility of such applications, paying attention especially to the signal transmission attenuation under conditions of fog and increased density of particulates in the line of sight.

Planetary remote sensing is just a level more demanding than remote sensing of the Earth surface. Here, we can perform spot checks to determine the emissivity of the surface emission or reflection element even though some areas might be difficult to access. Such spot checks are critical to calibrate the instrument and verify the algorithm performance. This capability is not available for general planetary exploration, except possibly for Mars (also the moon and now asteroids) where the sample return missions have been successfully executed. In order that we may classify the unknown surface and its temperature remotely, we need to develop a database that will include emissivity of representative materials that we anticipate to find on diverse planetary surfaces. Maturilli and Helbert describe the facility setup to characterize materials that we expect to find on other planets. They are paying particular attention to the error minimization of the measurement setup in emissivity measurements.

The Special Section on Advances in Infrared Remote Sensing and Instrumentation was conceived as an outgrowth of the SPIE yearly conferences held during the SPIE annual meeting in San Diego, California, with the same title. In fact, the special section includes papers from this series of conferences, other SPIE remote sensing conferences, and a few papers that are covering general topics related to this theme. We would like to express our appreciation to the editor-in-chief for inviting us to perform this enjoyable and important assignment. It is good to assess every few years the status of advancement of such an important technology and its accomplishments in keeping the Earth flourishing.

We found the experience of editing this special section highly rewarding: we enjoyed getting to know the details of some of the most accomplished research in the ever-more relevant and useful field of remote sensing. We thank the authors for contributing reports about their work to this special issue, and for responding to the journal requests in a timely fashion.

All papers went through a singly blind review process, having been evaluated by 2 or more reviewers: reviewer knows the authors but (s)he remains unknown to them. Some papers went through several review cycles. We thank all of the reviewers for their careful reading of the manuscripts and for providing constructive feedback to the authors and editors. The papers were much enhanced upon the authors' improvement, inspired by critical evaluation and feedback of the refereeing process.

Finally, we wish to express our appreciation to the staff of the *Journal of Applied Remote Sensing*. Working behind the scenes, they monitored with a personal touch the activities involved in publishing a refereed paper, from the initial submission to its final timely publication. They handled all of the correspondence with authors, reviewers, and kept the editor-in-chief informed of the process. They succeeded in making the editorial process appear effortless and flawless, efficiently running it without any noticeable glitches. We would not have been able to do it without them!

Marija Strojnik received her MS degrees in physics, optical sciences, and engineering, and her PhD degree in optical sciences. NASA awarded her six technology development certificates. She conceptualized, designed, and demonstrated an autonomous, star-pattern-based navigation technique, employing an intelligent camera, for *in situ* navigation decisions. For this discovery, SPIE awarded her the George W. Goddard award. She is a fellow of OSA and SPIE.

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