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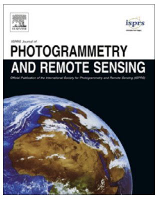

Review Article

Remote sensing platforms and sensors: A survey

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ABSTRACT

The objective of this article is to review the state-of-the-art remote sensing technologies, including platforms and sensors, the topics representing the primary research interest in the ISPRS Technical Commission I activities. Due to ever advancing technologies, the remote sensing field is experiencing unprecedented developments recently, fueled by sensor advancements and continuously increasing information infrastructure. The scope and performance potential of sensors in terms of spatial, spectral and temporal sensing abilities have expanded far beyond the traditional boundaries of remote sensing, resulting in significantly better observation capabilities. First, platform developments are reviewed with the main focus on emerging new remote sensing satellite constellations and UAS (Unmanned Aerial System) platforms. Next, sensor georeferencing and supporting navigation infrastructure, an enabling technology for remote sensing, are discussed. Finally, we group sensors based on their spatial, spectral and temporal characteristics, and classify them by their platform deployment competencies. In addition, we identify current trends, including the convergence between the remote sensing and navigation field, and the emergence of cooperative sensing, and the potential of crowdsensing.

1. Introduction

Remote sensing, in general, refers to any noncontact technique whereby the object space can be observed (Lillisand et al., 2015). Traditionally, the term remote sensing was used for satellite and airborne platforms, acquiring data typically by optical and radar sensors (Campbell, 2002; Schowengerdt, 2007). Most recently, any image and spatial data acquisition methods, including airborne surveying and photogrammetry (Mikhail et al., 2001), are considered to be remote sensing, though the terms satellite-based or airborne remote sensing as well as mobile mapping, for terrestrial platforms, are still occasionally used. Besides the primary grouping, which is based on platforms, remote sensing technology is characterized by the imaging sensor used, such as large-format aerial camera, and by application area, such as close range photogrammetry (Fraser et al., 2005; Martínez et al., 2013). Subsequently, the term remote sensing is used in an inclusive way to include all the traditional primary mapping data acquisition technologies. In general, as most image acquisition is based on the central projection model, the original 3D observation/object space is reduced to a 2D image domain in remote sensing; essentially, posing an inverse problem if 3D data recovery is required, such as in topographic mapping. With active sensors, however, 3D data may be directly obtained.

Due to unprecedented technological developments, the remote sensing field has been vastly expended in terms of applications recently, and in parallel, the performance has significantly improved too (Grün, 2008). In fact, to define the boundaries of remote sensing is getting harder as the observation space now includes many more areas besides the classical topographic mapping and land cover classification. Furthermore, it is a difficult task to organize the remote sensing technologies from the usual data acquisition perspective, as sensors have advanced and platforms have proliferated so much recently, and in many cases the systems are so tightly integrated that they do not fit traditional categories.

Remote sensing is a rapidly advancing technology, mainly driven by imaging sensor developments and endlessly increasing performance of the information infrastructure, including processing, storage and communication. In addition, new platforms are introduced, and, in particular, UAS (Unmanned Aircraft System, other known terms are UAV (Unmanned Aerial Vehicle) and RPAS (Remotely Piloted Aircraft System), note UAS, the more general term, is used in this paper) technology has seen unprecedented growth recently (Pajeres, 2015; Colomina and Molina, 2014; Watts et al., 2012). In fact, the rate of change has kept continuously increasing in the past five years, as new imaging sensors as well as powerful data/information processing methods have been

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introduced and, subsequently, significantly broadening the applications (Pajeres, 2015), resulting in strong growth in the remote sensing market (ASPRS, 2011). The rest of the paper is organized as follows. The Section 2 discusses the classical remote sensing field. Section 3 addresses the status and recent developments in platforms. Section 4 reviews the georeferencing aspect of remote sensing. Section 5 provides a review on the state-of-the-art active and passive remote sensing. Finally, Sections 6 and 7 show trends and outlook on remote sensing and platforms.

2. Remote sensing

The objective of any remote sensing technology is to provide observation of some physical parameter in a mapping frame at a given time or time period. The physical space is broadly defined and, from the shape of the Earth, includes man-made objects, vegetation, atmospheric parameters and anything in between. In terms of spatial and temporal resolution, there is a similarly wide range. Fig. 1 shows the observation range, as a cube, which is defined by three sensor parameters: (1) the spatial resolution, expressed in GSD (Ground Sampling Distance), (2) data acquisition frequency or revisit time, and (3) object range, the average distance between the sensor and the object space observed; note the spectral aspect of the sensors is not included.

While Fig. 1 provides a general orientation with respect to the main parameters, there are several additional conceptual and practical aspects to remote sensing platforms and sensors. Table 1 lists typical parameters for the most frequently used remote sensing systems. While the main sensors, such as active and passive imagers, are generally available on all platforms, the object range is mostly correlated to system complexity and performance as well as to price. Note that the relative price in Table 1 is related to system cost. It is remarkable that optical sensors, including panchromatic and MS (Multispectral) cameras, can provide nearly identical spatial resolution across the platforms. In contrast, the ground coverage, deployment time and range significantly vary by platforms. Noteworthy among the platforms is crowdsensed data, discussed later, such as still imagery or video data, which is becoming increasingly available, even from satellite platforms (SkyBox Imaging, 2013). Also, sensors fixed to static platforms are similar to sensors installed on mobile platforms, so are not separately listed; note that growth is strong in that category.

There are many important parameters that are specific to certain applications and not included in Table 1. For example, due to climate change related needs, bathymetric mapping is getting increasingly more attention recently (Brock and Purkis, 2009). Fluctuations in weather patterns cause flooding at unusual rate and volume, so modeling underwater surfaces that are needed for water flow estimation is essential to support disaster prevention. Similarly, including the object space complexity and platform motion characteristics into Table 1 is not feasible due to variability of these parameters. Object space occlusions, such as urban canyons, multipath, and reflections from planar surfaces, can pose difficulties in sensing at varying rates for different platforms. For example, emerging UAS platforms, working with shorter object ranges and slower speeds, are able to fly in between tall buildings and can provide significantly better observability compared to an airborne platform with predominantly vertical sensing capability.

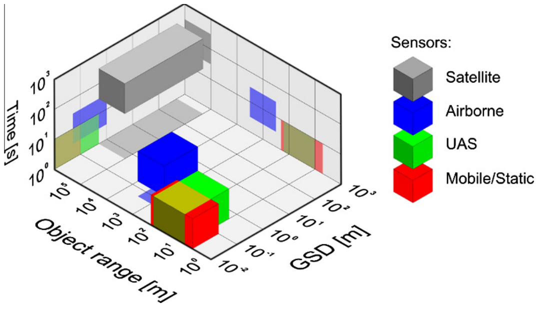

Fig. 1. Remote sensing observation cube.

3. Platforms and object space

The characteristics of the platforms carrying the remote sensors play a significant role in the sense of how efficiently the object space can be observed. The more evenly the observation space traveled by the platform, the higher the observability; ideally, a nearly constant object range could provide the remote sensed data at a consistent accuracy level. Clearly, it is not a realistic scenario to always achieve in practice. There are several ways to improve the observing potential from a platform. The most obvious solution is installing multiple sensors in different orientations on the same platform, such as forward and backward looking cameras and/or LiDAR sensors on mobile platforms (Petrie, 2009). This approach represents the current trend of multisensory systems. Not long ago, remote sensing systems were based on a single sensor, such as a large format camera on airborne platforms or a multispectral imager on a satellite. With advancement in sensing and computer technologies, sensors have become more affordable, and modern remote sensing systems use multiple sensors, including identical and/or different sensors, such as multiple cameras and/or LiDAR sensors (Asner et al., 2012; Nagai et al., 2009; Paparoditis et al., 2012).

A more conceptual approach to improve the observability is cooperative sensing. This idea is about multiple platform based sensing and represents the next step in the evolution that started with single sensor based remote sensing and then progressed to the current multisensory systems. Cooperative sensing is closely related to cooperative navigation (Pages et al., 2015), as both share the multisensory data obtained from multiple platforms in the same object space. The objectives are also similar: try to achieve a better trajectory and object space reconstruction using redundant multisensory data acquired from multiple platforms moving in cooperation, except the focus is on real time implementation for the cooperative navigation. Emerging remote sensing satellite constellations, micro satellite systems or the A-Train concept, discussed later, as well as UAS swarms are the early implementation of the cooperative sensing concept.

3.1. Satellite platforms

Spaceborne sensors have been around for more than 40 years (Lulla et al., 2012); Landsat-1 was launched in 1972, followed by SPOT-1 in 1986 and Ikonos in 1999. The latter heralded the era of commercial satellite systems. From that point, space technology rapidly advanced, and have now reached the price point where imagery acquired by these systems is truly affordable. In fact, there are currently about 50 countries operating land remote sensing satellites; note that remote sensing satellites represent a small segment of the communication satellite dominated spaceborne platforms. In the United Nations Office for Outer Space Affairs, where the outer space launches are recorded, there are currently more than 7000 records of launched objects and launch applications from 70+ countries and organizations (http://www.unoosa.org/oosa/showSearch.do). In the following, only the most important and emerging satellite systems are discussed. For more information on remote sensing satellites, see (https://directory.eoportal.org/web/eoportal/home).

Table 2 lists the main satellite categories with basic parameters based on typical samples; given the large number of satellites, only

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