Journal of Cultural Heritage xxx (2015) xxx–xxx

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

An overview of satellite synthetic aperture radar remote sensing in archaeology: From site detection to monitoring

Fulong Chen[a,b,*], Rosa Lasaponara[c], Nicola Masini[d]

[a] Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, No. 9 Dengzhuang South Road, Haidian District, 100094 Beijing, PR China
[b] International Centre on Space Technologies for Natural and Cultural Heritage under the Auspices of UNESCO, No. 9 Dengzhuang South Road, Haidian District, 100094 Beijing, PR China
[c] Institute of Methodologies for Environmental Analysis, National Research Council, C. da Santa Loja, 85050 Tito Scalo (PZ), Italy
[d] Institute for Archaeological and Monumental Heritage, National Research Council, C. da Santa Loja 85050, Tito Scalo (PZ), Italy

ARTICLE INFO

Article history:
Received 26 March 2015
Accepted 21 May 2015
Available online xxx

Keywords:
Synthetic aperture radar
Archaeology
Heritage
Detection and discovery
Monitoring and diagnosis

ABSTRACT

In the last two decades, archaeology has benefited from the development of earth observation (EO) technologies, including optical multispectral, LiDAR and synthetic aperture radar (SAR) remote sensing. The latter is gaining the attention of an expanding community of scientists and archaeologists due to the increasing availability of multi-platform, multi-band, multi-polarization and very high-resolution satellite SAR data. It is increasingly becoming an important tool in archaeology owing to specific characteristic of its operational modalities, e.g. all-weather, penetration, polarization and interferometry. However, compared to other EO technologies, SAR is encountering more difficulties in realizing its full potential for archaeological applications due to the greater complexity of data processing and interpretation tools. In this paper, SAR-based approaches for the reconnaissance of archaeological signs and SAR interferometry for the monitoring of cultural heritage sites are discussed. Ways and means to reduce complexity of data processing and interpretation tools are also explored.

1. Research aims

The paper deals with the state-of-the-art spaceborne SAR remote sensing for archaeology, including SAR-based approaches for the reconnaissance of archaeological signs and SAR interferometry for the monitoring of cultural heritage sites. It also discusses the optimization of SAR data for typical problems of archaeological researches.

2. Introduction

The availability of numerous multifrequency, multi-polarization and very high-resolution (VHR) satellite SAR data has opened a new era in the spaceborne radar technology. This is particularly important for a number of applications, as in archaeology, that was historically limited by low spatial resolution of the early satellite SAR sensors. Up to now, research based on spaceborne SAR data have been generally limited compared to that based on optical imagery, due to the scarce public availability of data, complexity of data processing and software and the difficulty of interpreting the results from an archaeological perspective. Today, satellite SAR has entered into a golden era of applications mainly due to the increasing availability of abundant historical archives and active satellite platforms, ranging from free of cost, as provided via Sentinel-1, to high-resolution data available through TerraSAR/TanDEM-X, COSMO-SkyMed, Radarsat-2 and ALOS PALSAR-2. The latter offers data at a scale of one meter or higher. Furthermore, a number of user-friendly commercial and open source software have been recently developed. We now have around twenty spaceborne SAR sensors operating (Table 1) and new SAR systems will be launched within the next 5 years assuring a rich availability of data for the coming years.

The use of multifrequency, multisensor, multitemporal, quad-polarization (as PALSAR-2) SAR data can provide powerful information for archaeological investigations [1] ranging from archaeological/historical landscape, former environment, site detection (buried or emerging archaeological remains) and monitoring. SAR can overcome limits of passive optical data in being able to sense a target at any time of day or night, and, to some extent,

* Corresponding author. Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, No. 9 Dengzhuang South Road, Haidian District, 100094 Beijing, PR China. Tel.: +86 10 8217 8198; fax: +86 10 8217 8915.
E-mail address: chenfl@radi.ac.cn (F. Chen).

http://dx.doi.org/10.1016/j.culher.2015.05.003
1296-2074/

Table 1
SAR system parameters.

SAR system	Band	Polarization	Incident angle (°)	Resolution (m)	Swath width (km)	Organization	Altitude (km)	Orbit inclination (°)	Launch year
SEASAT	L	HH	23	25	100	NASA	790	108	1978
SIR-A	L	HH	45	30	50	NASA	225	57	1981
SIR-B	L	HH	20–60	30	50	NASA	225	57	1984
ALMAZ-1	S	HH	30–60	15	20–45	RSA (PKA)	300	72.7	1991
ERS-1	C	VV	24	25	100	ESA	790	97.7	1991
JERS-1	L	HH	35	18	76	NASDA/MITI	568	97.7	1992
SIR-C	C, L	All	17–60	25	15–100	NASA	225	57	1994
X-SAR	X	VV	17–60	25	15–40	DLR/ASI	228	57	1994
ERS-2	C	HH	24	25	100	ESA	785	97.7	1995
SAR-SAT	C	HH	17–50	10–100	50–170	CSA	790	98.6	1995
PRIRODA	S, L	HH	35	30	120	RSA/DLR	394	51.6	1995
Radarsat-1	C	HH	10–59	10–100	50–500	CSA	796	98.6	1995
ENVISAT	C	All	20–45	30	50–400	ESA	800	100	1998
SRTM	C	HH	20–60	30	60	NIMA/NASA	233	57	2000
PALSAR	L	HH; VV; HV; VH	20–55	10–100	70–250	NASDA/MITI	700	98	2002
Light SAR	L	All	20	25–100	50–500	NASA	790	97.7	2003
Radarsat-2	C	All	20–60	3–100	20–500	CSA	796	98.6	2007
COSMO-Sky Med Scan SAR	X	One and two polarization modes (HH, VV, HV, or VH)	20–59	16–100	100–200	ASI	620	97.8	2007
COSMO-Sky Med Strip Map	X		20–59	3–20	30–40	ASI	620	97.8	2007
COSMO-SkyMed Spot Light-2	X		20–59	1	10	ASI	620	97,8	2007
TerraSAR-X Spot Light mode	X	(HH, VV), (HH/VV)	20–60	1	10	DLR-ASTIRUM	514	97.44	2007
TerraSAR-X Strip Map mode	X	(HH/VV), (HH/HV), VV/VH	20–60	3	30	DLR-ASTIRUM	514	97.44	2007
TerraSAR-X Scan SAR mode	X	HH, VV	20–60	18.5	100	DLR-ASTIRUM	514	97.44	2007
TerraSAR-X Staring Spot Light mode	X	HH, VV	20–60	Up to 0.25	4–5	DLR-ASTIRUM	514	97.44	2013
Sentinel-1 Strip Map	C	VV + VH HH + HV	20–45	5	80	ESA	693	98.18	2014
Sentinel-1 Interferometric Wide		HH VV		5 × 20	250				
Sentinel-1 Extra Wide				20 × 40	400				
Sentinel-1 Wave mode				5	20				
PALSAR-2 Spot Light	L	HH, VV, HV	8–70	1–3	25	JAXA	636–639	97.92	2014
PALSAR-2 Strip Map		HH, VV, HV (HH + HV), (VV + VH) (HH + HV + VV + VH)		3/6/9	50–70				
PALSAR-2 Scan SAR		HH, VV, HV (HH + HV), (VV + VH)		100	350–490				

National Aeronautics and Space Administration (NASA); Shuttle Imaging Radar-A (SIR-A); Shuttle Imaging Radar-B (SIR-B); Russian Space Agency (RSA); European Remote-Sensing Satellite-1 (ERS-1); European Space Agency (ESA); Japanese Earth Remote-sensing Satellite-1(JERS-1); National Space Development Agency (NASDA); Ministry of International Trade and Industry(MITI); Shuttle Imaging Radar-C (SIR-C); X-Band Synthetic Aperture Radar (X-SAR); Deutsche Forschungsanstalt fur Luft-und Raumfahrt (DLR); Agenzia Spaziale Italiana(ASI); European Remote-Sensing Satellite-2 (ERS-2); Search And Rescue Satellite Aided Tracking (SAR-SAT); Canadian Space Agency (CSA); Synthetic Aperture Radar Satellite-1 (Radarsat-1); Environmental Satellite (ENVISAT); Shuttle Radar Topography Mission (SRTM); National Imagery and Mapping Agency (NIMA); Phased Array type L-band Synthetic Aperture Radar (PALSAR); Synthetic Aperture Radar Satellite-2 (Radarsat-2); Phased Array type L-band Synthetic Aperture Radar-2 (PALSAR-2); Japan Aerospace Exploration Agency (JAXA).

Please cite this article in press as: F. Chen, et al., An overview of satellite synthetic aperture radar remote sensing in archaeology: From site detection to monitoring, Journal of Cultural Heritage (2015), http://dx.doi.org/10.1016/j.culher.2015.05.003