Analysis of Ground Based SAR Images Acquired In A Small Urban Area Using Diverse Polarization Configurations

G. Luzi
Remote Sensing Department
Centre Tecnològic de Telecomunicacions de Catalunya
Av. C. F. Gauss 7, Castelldefels, Spain
gluzi@cttc.es

N. Dematteis
Geohazard Monitoring Group
Institute of Research for Hydro-Geological Protection
National Council of Research Torino, Italy
niccolo.dematteis@irpi.cnr.it

***Abstract*——** **A Ku band-terrestrial radar interferometer with different polarization combination capability, including left and right circular polarization (CP), has been used to investigate the potential of different co-polar and cross-polar acquisitions for Terrestrial Radar interferometry (TRI), aiming at improving the monitoring of landslides in semi-urban areas. After some preliminary tests carried out to verify the responses of simple targets, Ground Based SAR images acquired in a test area affected by a landslide have been analyzed. The study of how different polarization combinations affect coherence and amplitude dispersion of natural media and man-made structures has been carried out to evaluate the potentialities of the different polarization observations, aiming at easing the identification of stable scatters.**

Keywords—: GB-SAR; Interferometry; Circular polarization;

I. Introduction

The use of Ground Based SAR (GB-SAR) interferometers, or more generally Terrestrial Radar Interferometers (TRI), as they are named when not exploiting SAR techniques, in the last two decades consolidated, especially for the monitoring of natural processes (i.e., landslides, glaciers), open mines, and artificial facilities [1,2]; usually, the main goal is to provide deformation maps, estimating the evolution of the surface kinematics. Although interferometry makes use of the differential phase information, also amplitude information is of main concern, to understand and interpret the scattering behavior in the radar image, but mostly to select good points from the interferometric point of view. In particular, the estimate and the behavior of two parameters, coherence (COH), and dispersion of amplitude (DA) is fundamental to classify the image pixels and areas where the use of the interferometric phase is reliable [3]. So far, excluding a few recent studies (e.g. those described in [4-6]), the polarization used in GB radar observations is the linear co-polar vertical (VV) one. A possible reason of this lack is the fact that most of the commercial terrestrial radar systems do not provide the multi-polarization capability, and the main use of these terrestrial apparatuses is focused on interferometric processing for deformation measurements, where polarization features so far have been considered of minor concern. Anyway, some commercial apparatuses have been recently upgraded with polarimetric capabilities [5].

In this context, this paper focuses on investigating the Circular Polarization (CP) response of natural and artificial media, considering that one of the features of this polarization choice is its ability to be less affected by multipath effect. It is well known that when the transmitted circular polarized wave is reflected from a surface it turns the handedness of the rotating electromagnetic field. After a bounce, the backscattered field propagates in the opposite direction with respect to the transmitted signal. Combining co-pol and cross-pol pairs of transmitting and receiving antennas, right-handed (RH) and left-handed (LH), expressed using the two acronyms: RHCP and LHCP respectively, the contribution of even or odd bounds can enhance or minimize. Natural and human-made media often exhibit non-regular surfaces and targets' distribution, and multiple reflections frequently occur. This reduced effect of multipath interferences is theoretically expected to provide better performances in terms of phase stability and targets identification [7]. On the other hand, circularly polarized antennas are not commonly used due to some drawbacks: a lower efficiency in antenna gain, a more complex design especially when CP is requested for large bandwidth, and hence a lower diffusion and availability, which often justify the preference agreed to linear antennas in measuring systems oriented to strictly operative applications.

This paper reports some experimental results obtained acquiring data through a terrestrial radar, using different combinations of linear and circular polarized antennas. The polarization diversity is evaluated with an empirical approach comparing and analyzing the different responses, looking for the main differences between circular and linear combinations. The goal is to investigate how different polarization combinations affect the coherence and amplitude dispersion of natural media, and in particular whether the circular polarization can improve the identification of stable scatters, a fundamental issue in terrestrial radar interferometry.

Fig. 1. (Left) Picture of the Radar system installation (VV mode configuration). (Right) Picture of the transceiver mounting the two circularly polarized antennas.

II. Experimental Setup

A. Used Radar and antennas

The measuring system used to carry out the experimental campaigns is a well-known commercial apparatus, the Ibis-L [8]. The experiments, consisting in acquiring the same scenario with different polarization combinations, have been carried out based on the rationale that, when the simultaneity of the acquisitions is not necessary, because the polarization properties of the observed media are supposed stable or slow varying with time, acquisitions with different polarizations can be obtained simply substituting the antennas in subsequent acquisitions: in this configuration, only the mutual antenna performances determine the polarization purity of the measurement.

To add horizontal linear polarization measurement capability, a 90º waveguide transitions (also known as "twist") has been mounted before the horn antennas. To acquire cross- and co- CP responses, two patch array antennas have been designed and manufactured at Centre Tecnològic de Telecomunicacions de Catalunya (CTTC); the design of the array is based on the combination of four linear polarization elements to produce, with an appropriate sequential rotation of the elements and the feeding network, RHCP and LHCP [7]: pictures of the radar transceiver and used antennas are shown as fig. 1; main parameters are resumed in table 1. In their operating band, from 16.9 GHz to 17.2 GHz, a good axial ratio, lower than 3dB, is guaranteed (this parameter is generally used for estimating the degree of circularity of a polarized antenna).

TABLE I. Main parameters of the radar system used to acquire GB-SAR data.

Central frequency/wavelength	17.1 GHz /0.0175 m
Transmitted signal	Continuous Wave Step Frequency
Bandwidth/Range resolution	300 MHz/0.5 m
Azimuth angular resolution	4.4 mrad
Maximum Range	4 km
Image Sampling frequency	6 minutes

III. Experimental Results

A. Test site

To evaluate the actual capability of the radar system in separating the different polarization configurations, several radar acquisitions in real aperture mode (RAR) have been carried out, analyzing the response of single targets: in [9] the reader can find a detailed description of the tests carried out to this aim. In this paper, we report some interesting results focused on the image applications, i.e. on the main outcomes obtained from the analysis of data acquired during a two days long GB SAR image acquisition. The scenario consists of a small village located in Northern Italy, at 1300 m asl, namely *Monesi di Mendatica*, where a large landslide occurred in November 2016, destroying the main road and several buildings, and causing the evacuation of all the inhabitants. The imaged area includes buildings, wooden fences, a slope covered by debris, and all it is surrounded by vegetation. In the centre of the picture, shown in fig. 2A, is clearly distinguishable the area collapsed during the landslide main event, composed of very heterogeneous material: e.g., bricks, rocks, roof pieces, undulated metal plates, soil. The radar data used in this study have been acquired during a monitoring campaign organized within a H2020 project (HEIMDALL Project Number 740689 [10]). Figure 2A shows a picture of the main imaged area where are indicated the zones marked also in the GB SAR amplitude image in radar coordinates, depicted as fig. 2B, corresponding to some specific targets; fig. 2C shows the amplitude (VV) of the radar image projected on the DSM of the monitored area. To evaluate the decorrelation affecting the different areas, two different set of images have been acquired, corresponding to two temporal scales, 3 hours and 24h long, respectively. The short one includes 20 images with several combinations, while the longer includes about 200 images (a 24 h lapse) focused on the linear vertical co-polar (VV) and the circular crosspolar . The range from the GB-SAR to the centre of the scene is approximately 300 m, and the elevation angle of the radar antennas is zero. The two analyzed parameters are: the temporal Dispersion of Amplitude (DA) and the Coherence (COH), which are the main parameters related to the statistical reliability of interferometric processing: high values of coherence and/or low values of DA are quality indexes related to the accuracy of the retrieved interferometric parameters.

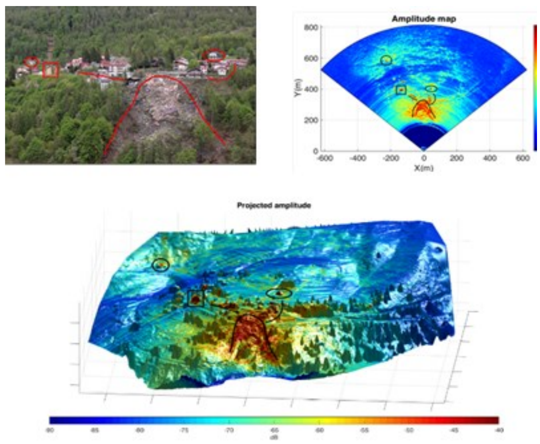

Fig. 2.A): Picture of the main area with indicated the areas marked in the amplitude image (B) where Amplitude image (VV) of a radar acquisition in radar coordinates with indicated some outstanding targets are shown. (C): Amplitude of the radar images projected on the DSM of the monitored area.

TABLE II. Tested configurations for the radar measurements.

Type	Symbol	Trans. Pol Antenna	Rec. Pol Antenna	#Acqu.
Copol	VV	Linear vertical	Linear vertical	20
Copol	RR	Circular right-hand	Circular right-hand	16
Crosspol	HV	Linear horizontal	Linear vertical	34
Crosspol	VR	Linear vertical	Circular right-hand	14
Crosspol	RL	Circular right-hand	Circular left-hand	22
Copol	VV	Linear vertical	Linear vertical	282
Copol	RR	Circular right-hand	Circular right-hand	185

B. The short time interval series

The sets of images here analyzed have been acquired during two hours for each configuration (see Table 2), according to the table 2 details. Figure 3 shows the DA and the COH of the five cases. From these plots, we observe the following main remarks. VV shows the lowest DA on buildings, as expected, but also on vegetation is low, probably due to the short temporal lapse analyzed: indeed, also coherence maintains very high values. In this specific case it is difficult to find out differences among different targets, and this configuration is not suitable to distinguish stable scatters for the interferometric processing, probably due to the short time span. The cross-polar HV shows high COH on buildings, but very low on vegetation. RL shows a low DA and high coherence on buildings, as for VV, considering that the coherence on the vegetation is low, RL can be used both for selecting interferometric scatters, and for classification purposes. It is also expected that RR configuration shows good coherence on buildings, and some specific targets where even bounces are present. Vegetation backscattering is very low, comparable with the noise of the areas where no radar targets are present. Furthermore, RR presents a high amplitude variability.

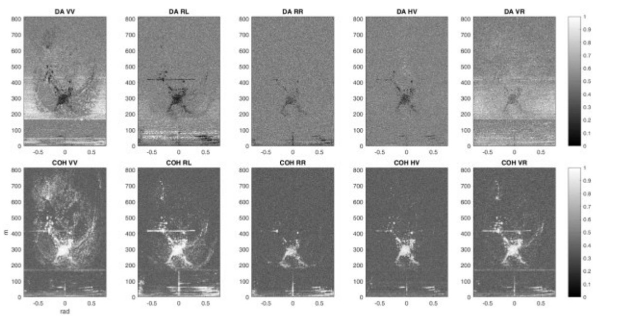

Fig.3. DA and COH for the different combinations analyzed in the short interval series of image acquisition. Map coordinates are expressed in meters for range direction, and radians for azimuth direction (After [9]).

Observing these results, the two configurations which show a good range of value for DA and COH, i.e low DA and higher COH, are VV and RL. This result is expected because in the case of the linear polarization, copolar combination gives the higher amplitude response, while in the case of the circular polarization, due to the prevalent single bound reflection, the crosspolar combination provides the higher response.

C. The long time interval series

An analogous analysis has been carried out using approximately 200 images for two configurations: linear copular VV, and circular cross-pololar RL for temporal Dispersion of Amplitude (DA) and the Coherence (COH); in Table 2, the configurations used for the long interval measurements are resumed

In general, DA of VV maintains a low value, and DA of RL is quite uniform and assumes in void areas values similar to the areas subjected by relevant decorrelation, such as wood or grass. The most interesting aspect is that COH RL is high on trees despite the large temporal interval for long series, and improves with respect to short measurements.

Calculating the probability density function (PDF) of three different ensembles, representing stable areas, changing areas and void, i.e. area where there is not backscattering and hence representing the noise, we observe that for DA in VV and RL, different behaviors are evident for the three sets (see Figures 5). The statistical analysis of these parameters based on the results shown in figures 5 confirms, that DA @ VV is able to separate the three classes, while DA @ RL does not distinguish between changing and void (fig 5a and fig. 5b).

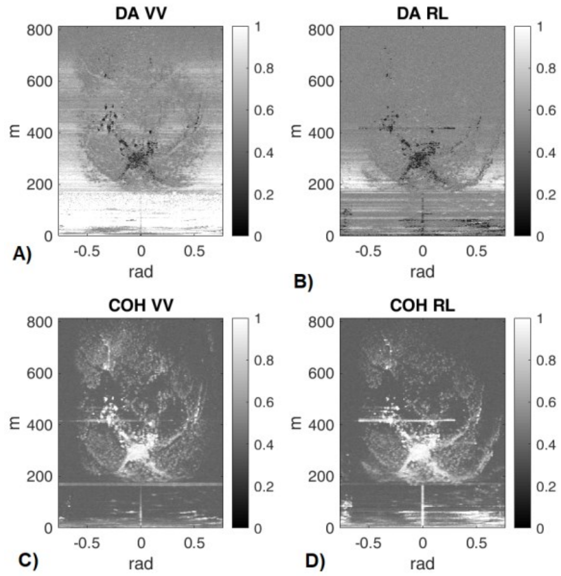

Figure 4. DA and COH for the two combinations analyzed in the long interval images series: VV and RL (After [9]).

On the other hand, COH @ RL candidates as a better parameter for the identification of stable points, showing higher values with respect to VV (see fig. 5 c and fig. 5 d), although further, and more exhaustive investigations are mandatory.

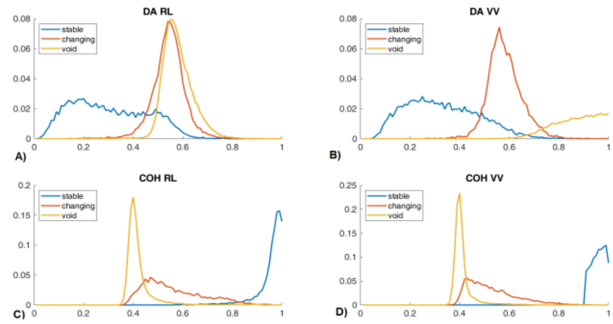

Figure 5. PDF calculated for the three classes: a) DA RL, b) DA VV, c) COH RL and d) CO VV. (After [9]).

IV. CONCLUSIONS

In this paper, we report some results obtained arranging a Ku GB-SAR usually employed for interferometric measurements of deformation, to provide multipolarization capability, although in non-simultaneous measurements. We focus on the radar response considering two main parameters, used to estimate the statistical reliability of the measured interferometric phase in radar interferometry: DA and COH.

In the short time interval data set, all the tested polarization configurations showed a sufficient dynamic range to detect specific targets. Coherence appears to be more suitable for image interpretations. Results demonstrate the effectiveness of circular cross-polarization, as an alternative of the typical VV linear combination mostly used. As far as the long time series, where the co-pol LP (V) and the cross-pol CP are compared, the main outcome is that the DA of RL is quite uniform and assumes in void areas values similar to the areas subjected by relevant decorrelation, such as wood or grass, while COH RL is high on trees despite the large temporal interval for long series. Form the PDF distribution analysis, it can be assessed that the use of circular polarization, despite a lower SNR, does not jeopardize the quality of the images. On the contrary, it provides a higher coherence on stable scatters.

ACKNOWLEDGMENT

The data collection in Monesi has been partially financed by HEIMDALL (Multi-Hazard Cooperative Management Tool for Data Exchange, Response Planning and Scenario Building), a Collaborative Project, Call/Topic H2020-s-2016-2017/H2020-SEC-2016-2017-1. Project Number 740689. Thanks are also due to the Municipality and Pro Loco of Briga Alta (CN) for their kind hospitality.

REFERENCES

[1] Caduff, R.; Schlunegger, F.; Kos, A.; Wiesmann, A., 2015. A review of terrestrial radar interferometry for measuring surface change in the geosciences. Earth Surf. Process. Landf. 40, 208–228.

[2] Monserrat, O.; Crosetto, M.; Luzi, G., 2014. A review of ground-based SAR interferometry for deformation measurement. ISPRS J. Photogramm. Remote Sens. 93, 40–48.

[3] Ferretti A., Prati C., and Rocca F., "Permanent Scatterers in SAR Interferometry," IEEE Transactions on Geoscience and Remote Sensing, vol.39, pp. 8-20, 2001.

[4] Iglesias R., Aguasca A., Fabregas X., J. Mallorqui, D. , C. López-Martínez, and Luca Pipia, Ground-Based Polarimetric SAR Interferometry for the Monitoring of Terrain Displacement Phenomena–Part I: Theoretical Description. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, VOL. 8, NO. 3, March 2015

[5] Baffelli, S.; Frey, O.; Werner, C; Hajnsek, I; Polarimetric Calibration of the Ku-Band Advanced Polarimetric Radar Interferometer, IEEE Transactions on Geoscience and Remote Sensing 56(4), http://doi.org/10.1109/ tgrs.2017.2778049

[6] Y. Izumi, S. Demirci, M. Z. Baharuddin, J. T. Sri Sumantyo, and H. Yang, Analysis of Circular Polarization Backscattering and Target Decomposition Using GB-SAR. Progress In Electromagnetics Research B, Vol. 73, 17-29, 2017.doi:10.2528/PIERB1608170

[7] Ferré, R ; Mira, F; Luzi, G; Mateu, J; Kalialakis, C; A Ku band circularly polarized 2× 2 microstrip antenna array for remote sensing applications. Proceedings International Applied Computational Electromagnetics Society Symposium – Florence Italy (ACES), 26-30 March 2017

[8] Coppi F., Gentile C., Ricci P., A software tool for processing the displacement time series extracted from raw radar data. In Proceedings of the 9th International Conference on Vibration Measurements by Laser and Non-Contact Techniques, Ancona, Italy, 22–25 June 2010.

[9] Guido Luzi and Niccolò Dematteis, Ku Band Terrestrial Radar Observations by Means of Circular Polarized Antennas Remote Sens. 2019, 11(3), 270; https://doi.org/10.3390/rs11030270

[10] Heimdall Collaborative Project Call / Topic H2020-SEC-2016-2017/H2020-SEC-2016-2017-1 Title Multi-Hazard Cooperative Management Tool for Data Exchange, Response Planning and Scenario Building. Project Number 740689 Project Acronym HEIMDALL