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***Abstract*— GB-InSARs (Ground-Based Interferometric Synthetic Aperture Radar) have been demonstrated able to detect changes and even the target elevation when they are provided with a mechanical system for rising the radar head. In this paper a novel acquisition mode is proposed that uses a GB-InSAR with a transponder for obtaining the target elevation, without the need to move the radar head.**

Keywords —digital elevation model, radar, synthetic aperture radar, interferometry

I. INTRODUCTION

Ground-Based Inteferometric Synthetic Aperture Radar (GB-InSAR) systems are popular remote sensing instruments for detecting changes in the ground [1]. Furthermore, these radars are able to estimate the target elevation when they are provided with a mechanical system for changing the height of the radar head [2] or when they are provided with two receiving antennas at different height [3]. In this letter the authors propose a novel acquisition mode that uses a transponder in combination with a linear GB-SAR for estimating the target elevation. This method exploits the vertical shift of a transponder instead of the movement of the radar head. It can be an advantage in applications where it is not recommended to reduce the mechanical stability of the radar head with a mechanical system for its vertical shifting.

II. WORKING PRINCIPLE

The basic idea is to use a transponder amplifier for operating a standard linear GB-SAR as a bistatic radar. The radar acquires a bistatic image of its own field of view exploiting the bouncing of the signal through the transponder (Fig. 1).

By changing the height (Δz_T) of the transponder it is possible to obtain two bistatic images, the interferogram of which contains the information about the quote (z_0) of the targets in the field of view. The transponder consists simply of two antennas and an amplifier.

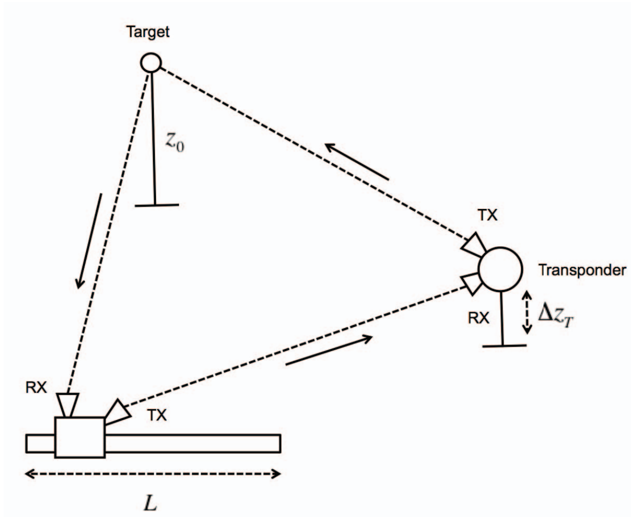

Fig. 1 Working principle of GBSAR with transponder

With reference to Fig. 2, the phase of a target (P) in a bistatic image depends on its distance from the point C, that is the intersection between the bisector of the bistatic angle β and the segment between the centre (O) of the linear scan and the transponder T. The angles β and α can be calculated as follows

$$\beta = \cos^{-1}\left(\frac{-\vec{R}_0 \cdot \left(\vec{R}_T - \vec{R}_0\right)}{\left|\vec{R}_0\right|\left|\vec{R}_T - \vec{R}_0\right|}\right) \qquad \alpha = \cos^{-1}\left(\frac{\vec{R}_0 \cdot \vec{R}_T}{\left|\vec{R}_0\right|\left|\vec{R}_T\right|}\right) \tag{1}$$

where $\vec{R}_0$ is the position vector of the target and $\vec{R}_T$ is the position vector of the transponder. By defining $\varepsilon = \pi - \alpha - \beta$ we obtain

$$\left|\vec{R}_C\right| = \left|\vec{R}_0\right| \sin\left(\frac{\beta}{2}\right) \Big/ \sin\left(\varepsilon\right) \tag{2}$$

where $\vec{R}_C$ is the position vector of the target of the C point. Therefore the Cartesian coordinates of C can be calculated as

$$x_C = x_T \frac{\left|\vec{R}_C\right|}{\left|\vec{R}_T\right|} \quad y_C = y_T \frac{\left|\vec{R}_C\right|}{\left|\vec{R}_T\right|} \quad z_C = z_T \frac{\left|\vec{R}_C\right|}{\left|\vec{R}_T\right|} \tag{3}$$

where (x_T, y_T, z_T) are the Cartesian coordinates of the transponder.

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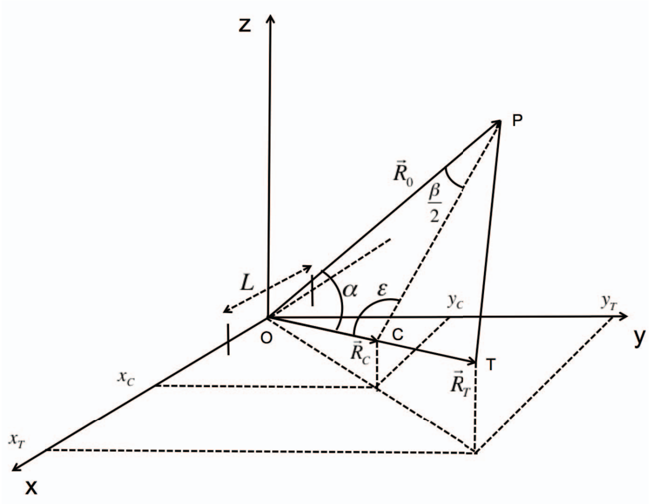

Fig. 2 Geometry of bistatic radar

The second image is acquired after a shift along z (Δz_T) of the transponder the effect of which is shown in Fig. 3

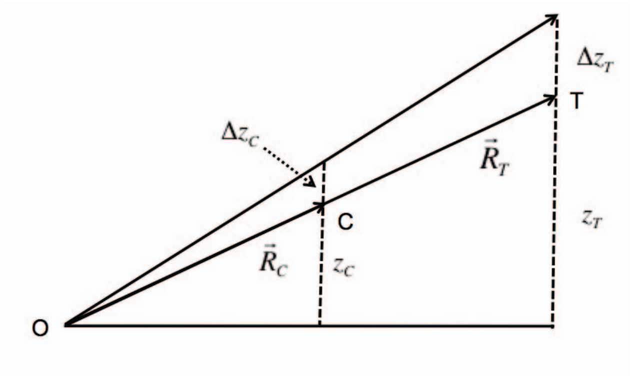

Fig. 3 Effect of a shift along z of the transponder T

Therefore the z-shift of the point C is

$$\Delta z_C = \Delta z_T \left|\vec{R}_C\right| / \left|\vec{R}_T\right| \tag{4}$$

For obtaining the height (z_0) of the target P, we can note that the electromagnetic path difference (Δs_0) of the target P in the interferogram between the two images is given by

$$\Delta s_0 = \Delta z_C \sin\vartheta_0 \tag{5}$$

with

$$\vartheta_0 = \tan^{-1}\left((z_0 - z_C) \Big/ \sqrt{(x_0 - x_C)^2 + (y_0 - y_C)^2} \right) \tag{6}$$

On the other hand, Δs_0 can be measured by the difference of phase ($\Delta\phi_0$) in the image of P as follows:

$$\Delta s_0 = \Delta\varphi_0 \frac{\lambda}{4\pi} \tag{7}$$

where λ is the wavelength of the transmitted signal.
Finally,

$$z_0 = z_C + \tan(\vartheta_0)\sqrt{(x_0 - x_C)^2 + (y_0 - y_C)^2} \tag{8}$$

that gives the height of the target P as a function of its difference of phase ($\Delta\phi_0$) in the interferogram between the reference image and the image taken with the transponder shifted in height of a known quantity Δz_T.

As the heights of the targets in the field of view are detected through interferometry, the possible phase ambiguity is an intrinsic problem. For avoiding ambiguity without using sophisticated algorithms of phase unwrapping [4], the condition to be respected is the following:

$$\Delta z_C < \frac{\lambda}{2(\sin\vartheta_0)_{max}} \tag{9}$$

where $(\sin\theta_0)_{max}$ is the maximum value of $\sin\theta_0$ for the targets in the field of view. On the other hand, the Δz_C should as larger as possible for minimizing the measurement error ($\delta\theta_0$) on the angle θ_0, indeed,

$$\delta\vartheta_0 = \frac{1}{\cos\vartheta_0}\frac{\lambda}{4\pi\Delta z_C}\delta\varphi \tag{10}$$

where $\delta\phi$ is the uncertainty in the phase measurement. Eq. (9) and eq. (10) pose severe constraints in the choice of Δz_C for a given measurement scenario.

III. THE RADAR AND THE TRANPONDER

Fig. 4 shows a sketch of the radar prototype we assembled. A vector network analyser (VNA) HP8720D operated as a transceiver providing a continuous wave stepped frequency signal (CWSF) in X-band with central frequency fc =10 GHz and bandwidth B = 160 MHz.

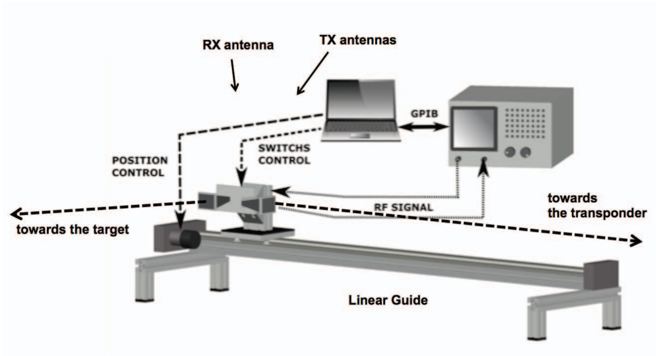

Fig. 4 The radar prototype

The transponder consisted of two horns and two wideband amplifiers (Nominal gain: 24 dB, Band: 6-18 GHz, Noise Figure: 5 dB) on a tripod. The two antennas were separated by a length of 0.6 m for minimizing the coupling and the possible oscillation of the transponder. The height of the transponder could be mechanically controlled.

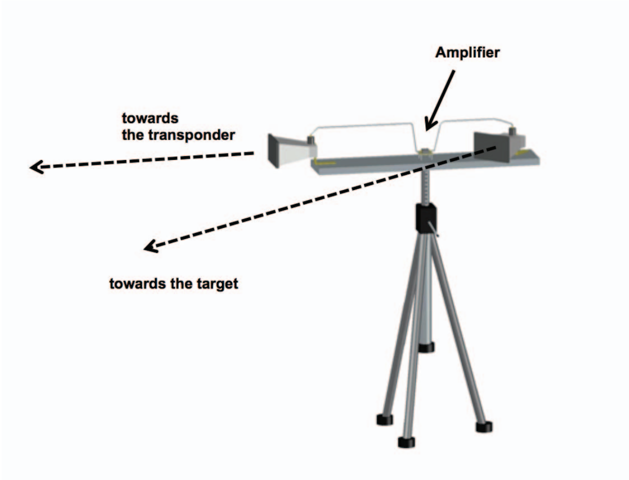

Fig. 4 The transponder

The bistatic radar images were focussed with a back projection algorithm that takes into account of the phase history of any path radar-target- transponder-radar [5],[6].

IV. Experimental Tests

For testing the capability of the bistatic GBSAR to evaluate the height of targets in its field of view, we raised a wood pole 5 m high on a grass in front of the radar (Fig. 5). The metallic base of the pole was covered with Eccosorb.

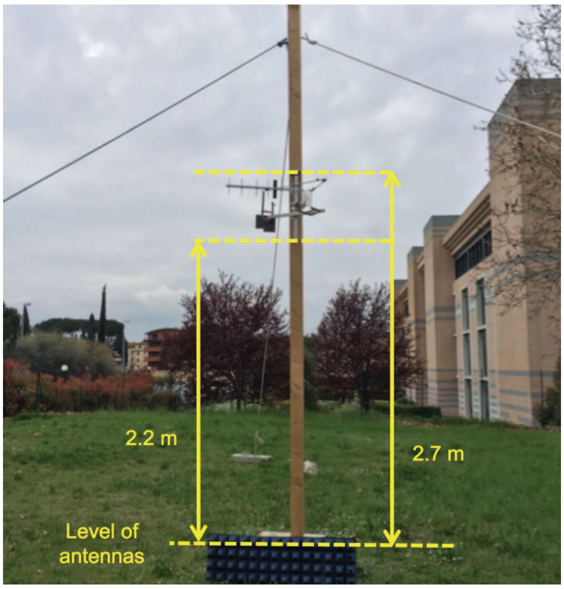

Fig. 5 Wood pole in front of the radar

The distance of the pole from the radar was 17.60 m. The target was an artificial set of metallic debris randomly disposed. Unfortunately, corner reflectors (the standard reference targets) are not effective targets in bistatic modality and spherical targets (that are isotropic even in bistatic modality) have too low radar cross section to be practical reference targets in in-field measurements. We performed two acquisitions, obtaining a reference image and an image with the transponder shifted in height of 4 cm. The measurement parameters we set were: scan length L =1.80 m; number of points along the scan length N_p =240, number of points of the frequency sweep: N_f = 801. Fig. 6 shows the obtained radar image in Cartesian coordinates relative to the first measurement. It is possible to identify the pole with the target and the metallic radar fence that encloses the garden where the radar operated.

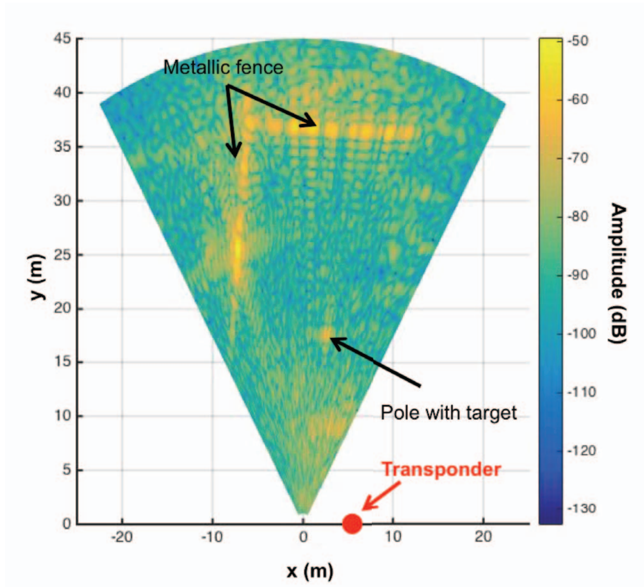

Fig. 6 Radar image

Fig. 7 shows a zoomed image of the pole in Polar coordinates (that are more suitable for processing this kind of radar images).

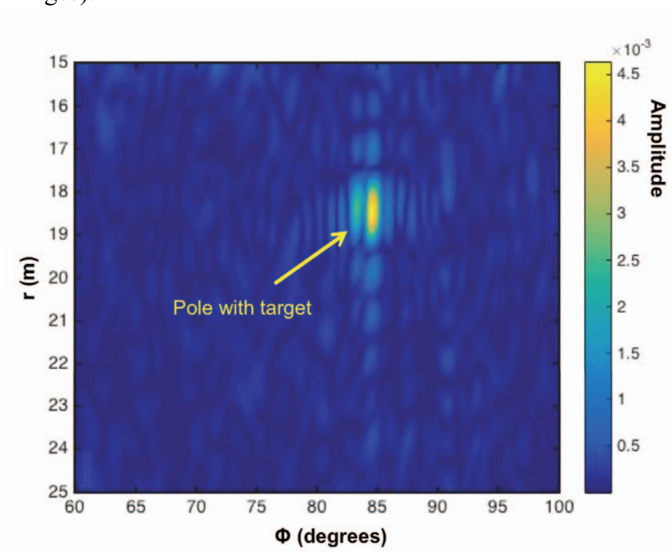

Fig. 7 Radar image of the pole in Polar coordinates

Fig. 8 shows the interferogram between the two radar images. Without any power threshold it is hard to distinguish the signal from the phase noise.

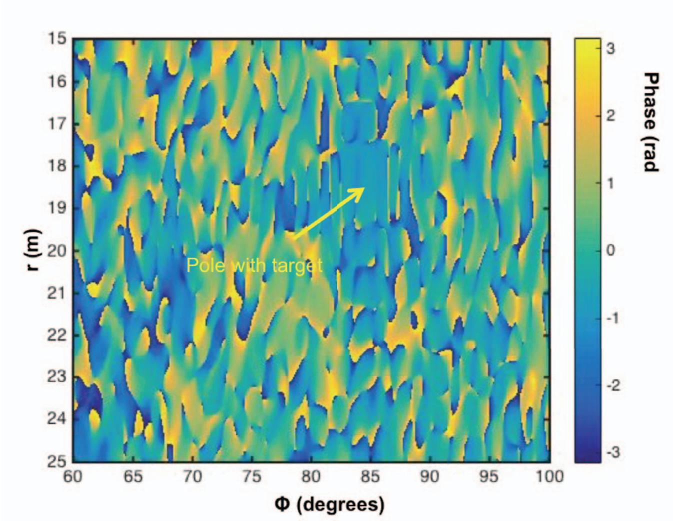

Fig. 8 Interferogram in Polar coordinates

Therefore we applied an amplitude threshold equal to 80% of the maximum. The height of the target obtained by eq. (8) was 2.59 m. The expected value was between 2.2 m and 2.7 m, that are the lowest and the highest edges of the target (see Fig. 5). As further test, we repeated the measurement by lowering the target by 1.0 m. The results of the two measurements are summarized in Table I

Lower edge of the target (m)	Higher edge of the target (m)	Measured height (m)
2.2 m	2.7 m	2.59 m
1.2 m	1.7 m	1.49 m

Table I Experimental results

V. CONCLUSIONS

Bistatic GBSAR has been demonstrated able to detect the target height with accuracy compatible with the nature of the target. This capability could be exploited for digital elevation model (DEM) production.

REFERENCES

[1] Caduff, R., Schlunegger, F., Kos, A., Wiesmann, A., “A review of terrestrial radar interferometry for measuring surface change in the geosciences.” *Earth Surface Processes and Landforms*, 2015, **40**, (2), pp. 208-228, doi: 10.1002/esp.3656

[2] L. Noferini, T. Takayama, M. Pieraccini, D. Mecatti, G. Macaluso, G. Luzi, C. Atzeni, C., “Analysis of ground-based SAR data with diverse temporal baselines.” *IEEE Transactions on Geoscience and Remote Sensing*, 2008, **46**, (6), doi: 10.1109/TGRS.2008.916216

[3] T. Strozzi, C. Werner, A. Wiesmann, U. Wegmuller, “Topography mapping with a portable real-aperture radar interferometer.” *IEEE Geoscience and Remote Sensing Letters*, 2012, **9**, (2), pp. 277-281, doi: 10.1109/LGRS.2011.2166751

[4] D. C. Ghiglia, M. D. Pritt. “Two-dimensional phase unwrapping: theory, algorithms, and software.” New York: Wiley, 1998.

[5] M. Pieraccini, L. Miccinesi, “ArcSAR: Theory, Simulations, and Experimental Verification.” *IEEE Transactions on Microwave Theory and Techniques*, 2017, **65**, (1), pp. 293-301, doi: 10.1109/TMTT.2016.2613926

[6] N. J. Willis, “Bistatic Radar” SciTech Publishing