Low-cost Corner Reflectors in Attempt to Measure Landslide in Doubrava City using Envisat ASAR Interferometry

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Abstract. The presented project works on evaluation of a slow landslide of a hill in Doubrava city, Czech republic, using satellite radar interferometry (InSAR). The hill is situated on place endangered by frequent flood activities. Since the hill is covered by a dense vegetation, it was necessary to utilize existing methods to overcome temporal and other decorrelation effects in processing C-band radar images from Envisat ASAR. The area will be processed by multitemporal InSAR techniques with filtering of radar wave delay through the atmospheric moisture using a GPS meteorology technique. To achieve more steadily reflecting points in five available ASAR images of the year 2010, specially designed corner reflectors were installed in the area of interest. They were mounted on hydrogeological drills every hour before acquisition time and then unmounted back, which is not a standard procedure since the needed radar wave phase is very sensitive to changes in the object position. This paper includes the description of designed corner reflectors together with results, main limitations and problems found of their appearance in the ASAR acquisitions. Possible errors in mounting of the corner reflectors and their turning to the satellite line of sight during sensing are depicted. The paper tries to figure out reasons of a partial failure of corner reflectors usage by investigating characteristics of their appearance in the images.

Keywords: Envisat, radar, corner reflectors, landslide, InSAR.

1. Introduction

A hill in Doubrava city, Czech republic with a height of 282 m and a slope of relative lift 70 m with steepness of about 30 m per 100 m distance is known to be sliding mostly due to the groundwater activity. The groundwater level is being monitored regularly by Geotest Corp. using hydrogeological drills. The landslide activity is gradually decelerating but seems to be still active. The groundwater activity is at its peak during strong rains and floods that occasionally happen in the area.

The idea of this project is to detect and measure the velocity of the landslide using satellite data. Since the hill is covered by vegetation, the radar interferometry (InSAR) results from Envisat ASAR images are totally depreciated by temporal decorrelation and therefore it cannot be monitored this way. The aim of this project was to overcome this limitation by installing corner reflectors on the site and so evaluate the slope movement during the year 2010. The hill wasn't monitored geodetically, unfortunately it wasn't possible to compare the interferometrical results with a ground truth. Anyway, in several scientific publications the methodology has been proven as reliable and the results could achieve a centimeter match (supposing high signal-to-noise ratio) in comparison with the levelling data in the areas of a slow deformation activities that are similar to expectations of this project area of interest. In addition, to achieve as confident results as possible, the GPS was also active during the Envisat acquisitions to perform zenith wet delay estimation from GPS meteorology technique to filter the phase errors due to radar wave delay through the atmosphere moisture.

Since there was only a short time dedicated to the processing when writing this paper, the presented are only preliminary results, without InSAR estimations that need to be further completed.

2. Design of corner reflectors

Usage of corner reflectors was already documented in many scientific papers as a technique with successful results. Corner reflector (CR) is an object designed to reflect the received radar wave in the exactly same direction. Several types of corner reflectors exist. The optimal reflection is ensured by appropriate geometrical setting and orientation of the reflector and a smooth material with a high dielectric constant.

As a material, the aluminum with a dielectric constant of around 9 (enough to avoid penetration of the radar wave) was chosen to create a trihedral corner reflector with square sides of 80x80 cm (see Figure 1). The computed theoretical radar cross section (RCS) of the reflector using Eq. 1 – cit. Hanssen, Ramon F. (2001) is RCS=36.92 dB. To detect the corner reflector on the SAR image, at least 15 dB difference amongst surrounding pixels should be ensured.

Additionally, a special mounting mechanism was designed to mount the CR directly on the hydrogeological drill, with a possibility of setting of the view angle (this was designed for the possibility of using the same CRs also for other satellites in the future).

The corner reflector is designed to be as smallest as possible with keeping its proper functionality to allow its economically effective reproduction on other projects.

$$RCS = \frac{12\pi \cdot a^4}{\lambda^2} \tag{1}$$

a length of each side of the trihedral CR
λ SAR wavelength (Envisat ASAR: 5.62 cm)

3. Acquisition planning, installation on site

Only five Envisat ASAR acquisitions of Doubrava surroundings could be planned for the year 2010. On 22nd October 2010 Envisat has changed its orbit descending of 17.4 km. There is no inclination drift control anymore, the perpendicular baselines can reach values even 20 km, while the limit for InSAR is around 1 km. Only areas in 38 degrees of latitude are covered by InSAR available acquisitions – cit. Miranda, N. (2010).

Acquisitions were planned in advance for the year 2010 (until the October). Because of conflict with projects of higher priorities, the acquisitions of 15th February and 22nd March couldn't be ordered and the acquisition of 26th April had to be achieved in H/H polarization mode (means sent and received horizontally oriented radar wave) while other executed acquisitions at 31th May, 5th July, 9th August and 13th September had to be ordered in polarization V/V (vertical sent and received polarization). In the end, only 5 acquisitions could be ordered that will include installed corner reflectors. Normally it is not eligible to combine images with different polarization interferometrically since the physical objects reflect such waves in different ways, based mostly on different geometrical orientation. But in the case of corner reflectors this is theoretically of no concern because if the reflectors are oriented correctly, they would reflect both waves identically.

The corner reflector is designed to be mountable directly on a hydrogeological drill. Three CRs have been constructed to be deployed on two drills on the observed hill and third on a stable place in the center of Doubrava city as a reference point. Because the drills are situated on an unsecured area that is visible from a nearby road, the CRs couldn't be installed permanently during the whole year. Because its construction enables to mount the CRs again on the identical location, the CRs were always mounted on place only in the acquisition day and were carried away afterwards. It wasn't practically possible to orientate the CRs identically in every installation. That's why we have to count with a lower precision of the interferometrically estimated landslide velocity, even that the theoretical tolerance of the CR orientation to the satellite line of sight to achieve its strong reflection is relatively broad – even 5 degrees difference between the CR centerline and the satellite line of sight in the azimuth direction will provide sufficient reflection - cit. Norris et al. (2004).

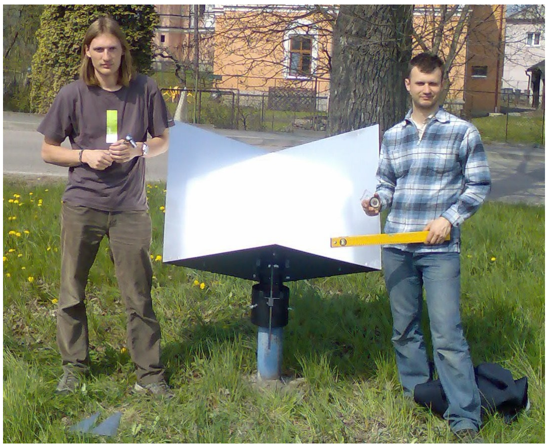


Figure 1. Corner reflector mounted on a hydrogeological drill V-100 (reference location in Doubrava city center).

The setting of corner reflectors turning was done by utilizing electronic compass onboard GPS with north direction set to True North of WGS-84 ellipsoid definition, the vertical direction was set as by tilting of corner reflector basement from horizontal spirit level tool. The values of the vertical tilt and azimuthal direction of the corner reflection three-dimensions related center line to the satellite line of sight were set according to these:

Direction to the satellite was computed using informations about the extent of Envisat ASAR images. The scanning was regarded to be perpendicular to the satellite line of sight (LOS). The projection of the LOS as the northern extent border in WGS-84 coordinate system was described by the border end points coordinates x_1,y_1 and x_2,y_2. Resulting azimuth (direction from the True North) was set as 98° 34' 8.76" using Equation 2.

$$azimuth = 180 \cdot \frac{atan|y1 - y2|}{atan|x1 - x2|} + 90 \quad (2)$$

The ASAR squint angle was computed for typical average Doppler centroid focusing value 400 MHz using Equation 3.9 from Hlaváčová, Ivana (2008) – as 0° 5' 9.5994" from the direction of satellite LOS. This was regarded as a too small angle to be counted in.

The vertical angle was computed simply using data about local incidence angles. For all the placemarks the Envisat ASAR incidence angle was 21° 51' 52" ± 15". Computed angle of the CR basement from the horizontal plane is therefore 23° 8' 7" ± 15" to achieve the directivity of the 45° CR center line pointing into the direction to the satellite LOS (the tolerance 15" has been ignored for practical setting, regarded as small).

4. Corner reflectors evaluation

In order to evaluate the corner reflectors behavior in the Envisat ASAR IMS (image mode medium resolution single look complex product) images, these images had to be pre-processed. The images were coregistered into a stack on a pixel level. The IMS files are processed without antenna pattern correction, only external parameters are included within the image file. Because the measured physical quantities are usually distorted by the sensing instrument and the transmission channel, the data must be calibrated with regard to the antenna pattern gain, transmitted chirp power, factor needed for digitization, to geometric attenuation and for the look angle – cit. Maitre et al., 2008. Therefore, the intensity values were radiometrically calibrated using ESA provided auxilliary files, then converted to dBs to make the images comparable between each other – to achieve a pixel radar reflectivity. For the radiometric calibration, the Equation 3 was used – cit. Rosich and Meadows (2004).

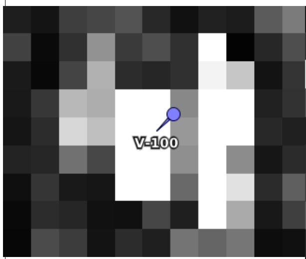
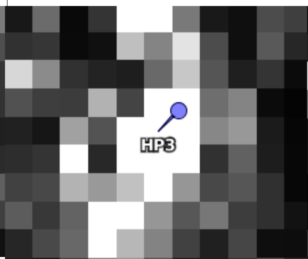
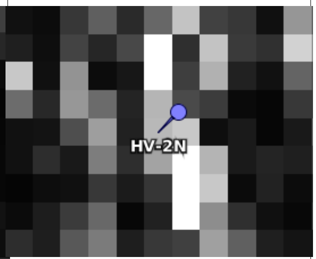
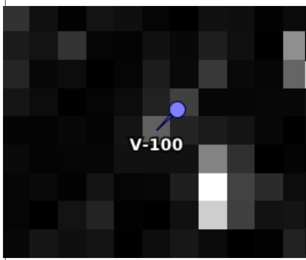
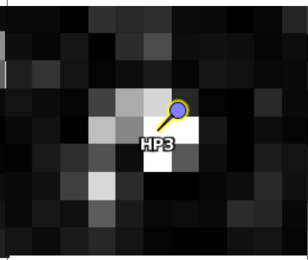
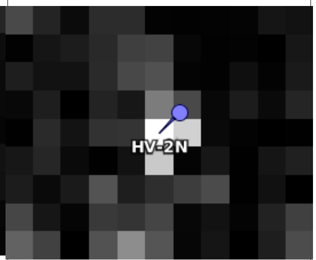
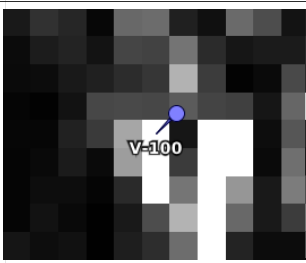
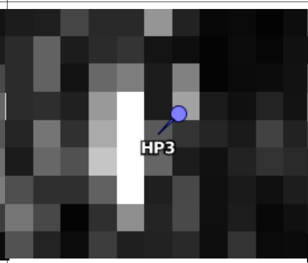
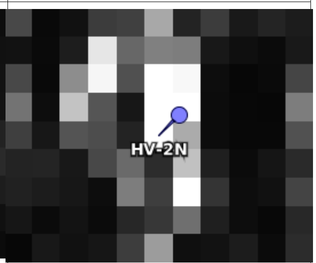
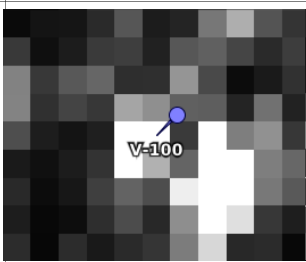
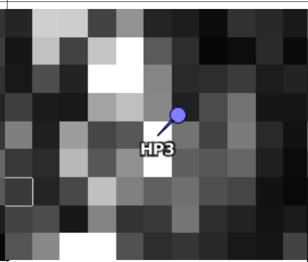
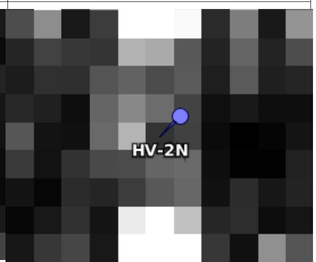
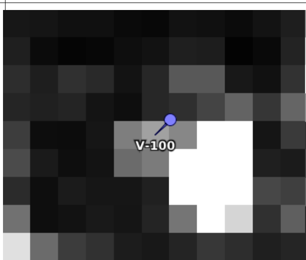
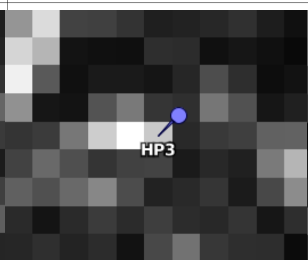
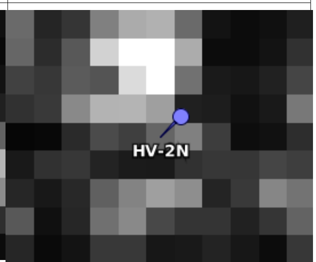
$$\sigma^0_{i,j} = \frac{DN^2_{i,j}}{K} \frac{1}{G(\theta_{i,j})^2} \left(\frac{R_{i,j}}{R_{ref}} \right)^3 \sin\left(\alpha_{i,j}\right) \tag{3}$$

$DN_{i,j}$	intensity of pixel i,j
K	radiometric constant
$\alpha_{i,j}$	incidence angle
$R_{i,j}$	slant range distance
R_{ref}	reference slant range distance
$\theta_{i,j}$	look angle
G	antenna pattern gain

The corner reflectors were found using the known WGS-84 coordinates. The reference ASAR image, chosen as 2010-05-31 for its optimal configuration regarding interferometric baselines (this image will be used also for interferometric processing in the future work), has been reprojected using range-Doppler terrain correction algorithm to match with the SRTM DEM coordinates in WGS-84 system. Using only available precise orbit files leads to coregistration errors. This was firstly tested, achieving a deviation of 15.2028" in longitude and 1.5516" in latitude, which corresponds with an error of 308 m (converted and measured in national S-JTSK coordinate system). After the terrain correction, the corner reflectors were coarsely identified, together with their radar coordinates.

In the Table 1, each CR is depicted as a pin as identified in the reference image. The value of intensity reflectivity in dB is a value of the most reflecting point in the pin 1 pixel neighbourhood, supposed to be the real corner reflector in each image (i.e. not mixed with patterns known to be caused by other nearby objects).

Table 1. Reflectance of the corner reflectors and their neighbourhood during all the 2010 acquisitions.

Date of acquisition	V-100	HP-3	HV-2N
26.4.2010	 8.49 dB	 10.80 dB	 2.89 dB
31.5.2010 (reference image)	 (not installed)	 9.32 dB	 4.55 dB
5.7.2010	 4.14 dB	 2.42 dB	 2.74 dB
9.8.2010	 2.97 dB	 1.17 dB	 2.41 dB
13.9.2010	 -2.69 dB	 -0.44 dB	 1.43 dB

In the presented overview of corner reflectors and their behavior in the radiometrically calibrated images we can observe a very different reflectivity and mislocation. Since the reflectivity should be comparable after the calibration, and it is regarded to be at least very similar in all of the cases, we have to admit that these corner reflector measurements are not perfectly usable. In the image scene we have found a strong reflector that corresponds to a house with a metal roof. Its reflectivity values in all the acquisitions were investigated to confirm the proposed compare methodology. This reflector's σ_0 values all get about 35dB ± 2.5 dB. The reflector position is the same in every image.

The Figure 2 depicts a probable reason of mislocation of the corner reflectors within the pixels. Because of a slight change in the view angle of the installed corner reflector, its reflectivity peak differs and can propagate into another pixels in the azimuth direction.

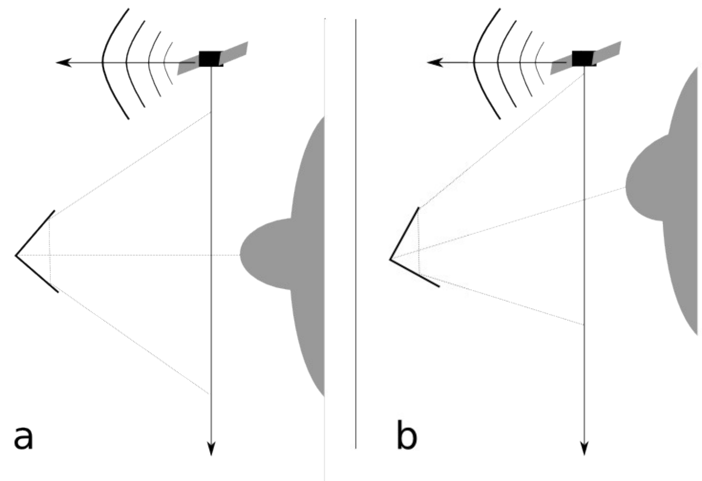


Figure 2. Radar response on corner reflector rotation. a – correct turning perpendicularly to the satellite line of sight, b – deviated CR turning causing reflectivity peak change in azimuth direction

5. InSAR processing methodology

Because of the depicted problems with the corner reflectors in the acquisitions, the usage of original StaMPS software to detect and determine the deformation velocity of the area of interest failed to pick the pixels containing the corner reflectors. The area is handicapped by a strong decorrelation mostly due to the vegetation cover, there was a strong atmospheric moisture during the acquisitions. That's why the StaMPS processing has failed using only 2010 images. Also, only 5 acquisitions are hard to investigate with standard multitemporal methods that assume usually 15 or more acquisitions to achieve a reasonable overview about terrain deformation in time. That's why also acquisitions from 2009 without mounted CRs are to be added for next StaMPS processing.

Since all the Envisat ASAR interferograms ended with a full loss of coherence, there are no interpretable results to be presented in this paper. But, for a orientation view, a non-actual interferogram from Alos PALSAR images is available, depicted on Figure 3.

Because of a longer wavelength (23.6 cm) that penetrates through the vegetation much easier, the hill is visible in the Alos PALSAR interferogram. This interferogram shows a relative terrain changes in the period between 27-01-2008 and 13-03-2008 (46 days) with a scale of 11.8 cm per one colour cycle. The monitored hill is located in the area visible as a reddish mark in the north-west part of the image. This can be interpreted as a detected slope movement of several centimeters towards the satellite line of sight, i.e. the landslide could be moving slightly to the west or it can be an uplift. Unfortunately, due to relatively large perpendicular baseline between acquiring satellite position (493 m) the interferogram is more sensitive to the topography. Therefore this artifact will be interpreted as caused only by a DEM error.

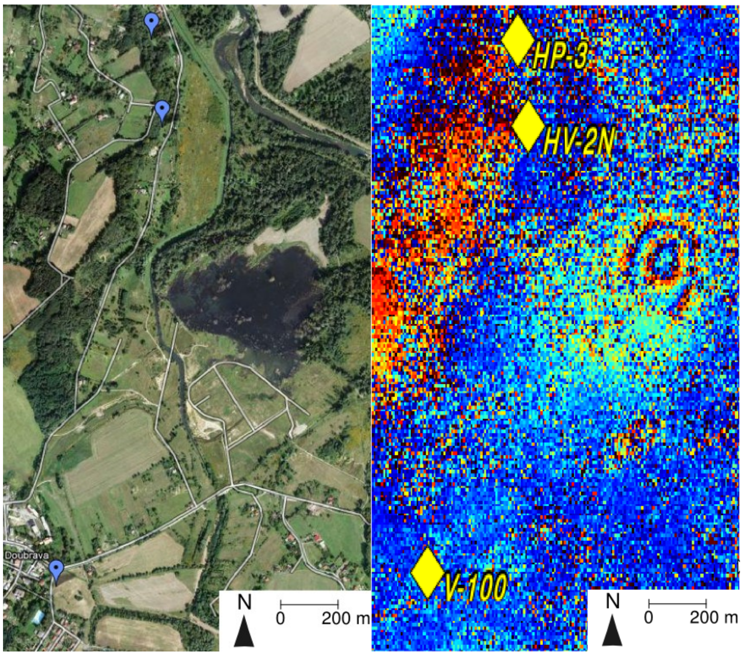


Figure 3. Locations of installed corner reflectors in Doubrava. Right part represents Alos PALSAR interferogram between 27-01-2008 and 13-03-2008.

6. Conclusions and future work

As a future work, only the pixels containing the corner reflectors will be evaluated using Persistent Scatterers (PS) technique as implemented in StaMPS, using partially edited scripts, together with results from GPS meteorology technique to filter the atmosphere delay from the GPS observations on site. More points with a stable amplitude dispersion will be identified automatically in order to densify the PS network and to evaluate the landslide activity in the Doubrava city, using also images from 2009.

Even that theoretical reflectance of the CRs is more than 36 dB, in the images the CRs exhibit reflectance of only 2-10 dB. This could have been caused by improper installation on the site. The reasons of this low reflectance will be further investigated.

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