InSAR analysis and Corner Reflector Experiments for Infrastructure Stability Monitoring Using Sentinel-1 Imagery

Zahra Sadeghi[1], Stephan Hobbs[2], Mushfiqul Alam[2], Michael Seller[2], James Deas[3], Sean Coleman[3] and Lucy Kennedy[1]

1 Spottitt Ltd., Electron Building, Fermi Ave, Harwell, UK

2 School of Aerospace, Transport & Manufacturing, Cranfield University

3 Strategy and Innovation, Network Strategy and Operations, Electricity Transmission, National Grid

National Grid Energy Transmissions (NGET), which owns and maintains the high-voltage electricity transmission network in England and Wales, conducts invasive analysis annually to monitor the towers most at risk of movement. Moreover, the NGET inspection teams perform annual line walking activities and monthly substation inspections during which they visually assess the presence of asset motion. These interventions are crucial to avoid issues which may cause expensive assets replacements or reconstruction. It costs NGET over £6 million per year to monitor only 1% of their most at risk assets.

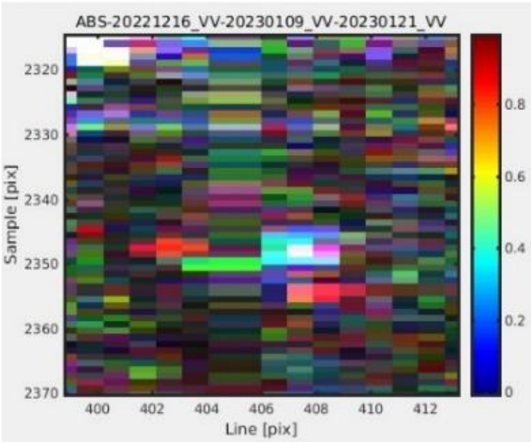
Synthetic Aperture Radar Interferometry (InSAR) is an accurate Earth observation method to monitor an asset's stability at a much lower cost and without the need to have physical access to the assets. This technique uses SAR satellite datasets e.g., Sentinel-1 which is freely available from the European Space Agency (ESA). Persistent Scatterer InSAR (PSI) is a novel technique to select strong, stable scatterers that remain coherent for the entire time series of radar acquisitions (Ferretti et al. 2001). In this study, we first applied conventional PSI analysis using SARPROZ software (Perissin et al.,2011) across three NGET areas of interest which each included 80 km of overhead lines (OHLs) and some underground cables and overground substations. To monitor an asset's stability using the PSI technique, it must be possible to identify at least one data point that can be accurately and definitively assigned to the asset itself. Some assets, depending on their characteristics (e.g. size, orientation, roughness and material) and their scattering behavior are 'natural reflectors' providing a strong and coherent back scattered signal that can be used for PSI asset motion analyses, but not all. One of the results of this study was an insight into the high % of towers that are not 'natural reflectors' and a study of how this issue could be solved by the installation of corner reflectors.

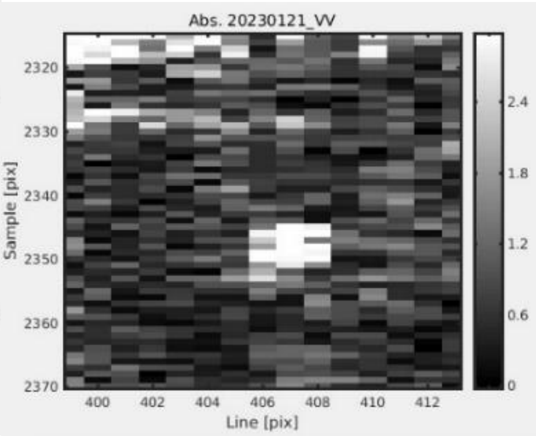
Corner reflectors (CRs) can be used to enhance the backscattered signal from the target where the signal is not strong and coherent enough to be selected as a Persistent Scatterer (PS) point (Cigna et al., 206 and Kelevitz et al., 2022). Therefore, in the next phase, we focused on designing and installing a number of CRs both on National Grid pylons, and a test site at Cranfield University, to assess their ability to make NGET assets, in particular tower monitorable when using PSI derived from free and open-source Sentinel-1 imagery. This project also set out to determine what the minimum distance between two installed CRs would need to be to still get two separate signals and therefore two distinct asset motion measurements from one single asset. We designed the CRs for these experiments to be clearly visible in images for a typical UK rural landscape away from woodland. Assuming a low vegetated background and a signal to noise ratio (SNR) equals to 10, five trihedral CRs with an inner side length of 70 cm were manufactured. In the installation phase, the CRs were fixed rigidly to a support and pointed towards the Sentinel-1 selected tracks using the local incidence angle and azimuth angle.

We mounted three CRs at the Cranfield University site, on 15th Dec 2022 in an open grassy area south-west of the runway in an L shaped formation (60 m along track and 20 m across-track), each with a 100% clear view to the Sentinel 1 satellites. We compared the amplitude time series of the pixel in which each CR was located in the three images taken before CR installation with four images taken after installation. Before doing the amplitude time series analysis, we co-registered all Sentinel-1 SLC images track 81 descending with respect to the first image after the first CR installation and georeferenced the images using a high-resolution LiDAR DEM, and finally manually corrected georeferencing using a visible feature in the SAR image. The result of this analysis confirms that the installed CRs have a strong back scattering signal towards the satellite in comparison to the background before the installation which matches with what we expected. We then proceeded to reduce the distances between the CR's in the North-South (along track) and East-West (across track) directions, with two experiments-30 m along track and 10 m Across-track on 9 Jan 2023 and 5 m and 10 m in across track on 21 Jan 2023 (table 1). The results showed that as long as the spacing is more than approximately 30 m (N-S) or 7 m (E-W) then the reflectors should be visible in the amplitude images as distinct targets. As the targets merge, it is probably possible to detect that more than one reflector is present, but this may require more than a simple visual inspection to be confident of the result. To better distinguish the signal of the two overlapping CRs in the amplitude image after installation, we applied amplitude time series analysis for all the pixels in the large bright area. The time series analysis confirmed a jump of amplitude after the CR installation for the pixels belongs to the CRs. Moreover, we applied an RGB colour composite analysis using the images before and after each installation which helped to distinguish the pixels corresponding to the installed CRs. Figure 1a) shows the RGB color composite analysis for the third CR installation using the image after the first installation (20221216, I1) as red, the image after the second installation (20230109, I2) as green and the image after the third installation (20230121, I3) as blue. Figure 1.b) shows the amplitude image on 20230121 after the third installation and figure 1.c-d) shows the amplitude time series for the pixels belonging to the three launched CR at the third experiment.

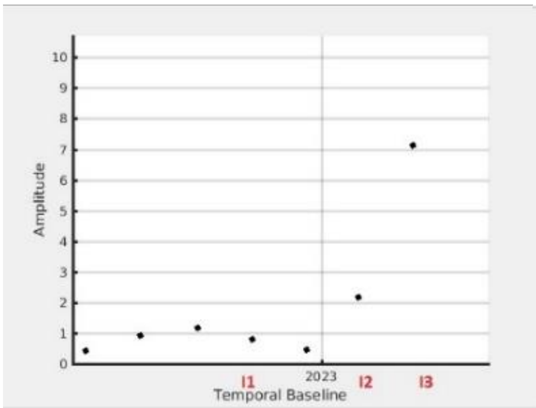
Table 1 Minimum CR distance trial results.

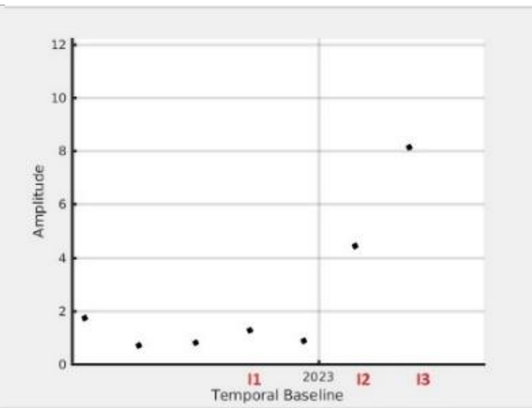
Date	**Along-track (N-S)**	**Across-track (E-W)**	**Comment**
16 Dec 2022 (I1)	60 m	20 m	3 distinct signals
28 Dec 2022			No reflectors deployed; clear background
9 Jan 2023 (I2)	30 m	10 m	3 signals but starting to overlap
21 Jan 2023 (I3)		5 m, 10 m	at 5 m spacing signals overlap, at 10m spacing signals starting to overlap



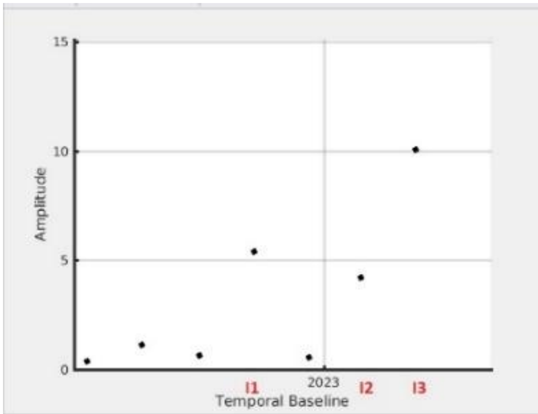


(a) (b)





(c) (d)



(e)

Fig. 1. (a) RGB colour composite of the third installation (b) amplitude image of Cranfield CR's captured 21 Jan 2023 (b), Amplitude time series of the installed CRs in Cranfield before and after installation, (c,d,e), I1, I2 and I3 are images on 20221216, 20230109 and 20230123.

The second test site was the National Grid Deeside Innovation Center, there we installed one CR on Tower 1 on 2nd Nov 2022 on the southernmost leg with a 100% clear (unobstructed by the body or arms of the tower or any other nearby object) view to the Sentinel 1 satellite with descending direction (track 52). The visual inspection of the amplitude images before and after installation shows no obvious change, therefore we analyzed the amplitude time series of the pixel in which the CR was located. We compared the three images taken before CR installation with the four images taken after installation. The result of this analysis clearly shows that there is a jump in amplitude of the reflected signal from the pixel in which the CR is located after installation. The signal of the CR in the amplitude image is not as significant or visually obvious as the CRs installed at Cranfield. This is likely due to the power of background clutter at Deeside which is higher than the Cranfield site which has a grassy field as it's background. Having located our first CR in the optimal position on a tower with a 100% clear view the team wanted to test a much more challenging CR location. The second test CR was installed on Tower 2 on 7th Dec 2022 on the west facing leg with a 0% clear (fully obstructed by the body and arms of the tower) view to the Sentinel 1 satellites. As anticipated due to the obstruction caused by the tower body there was no amplitude increase post CR installation that was either visible to the naked eye or visible in amplitude time series analysis.

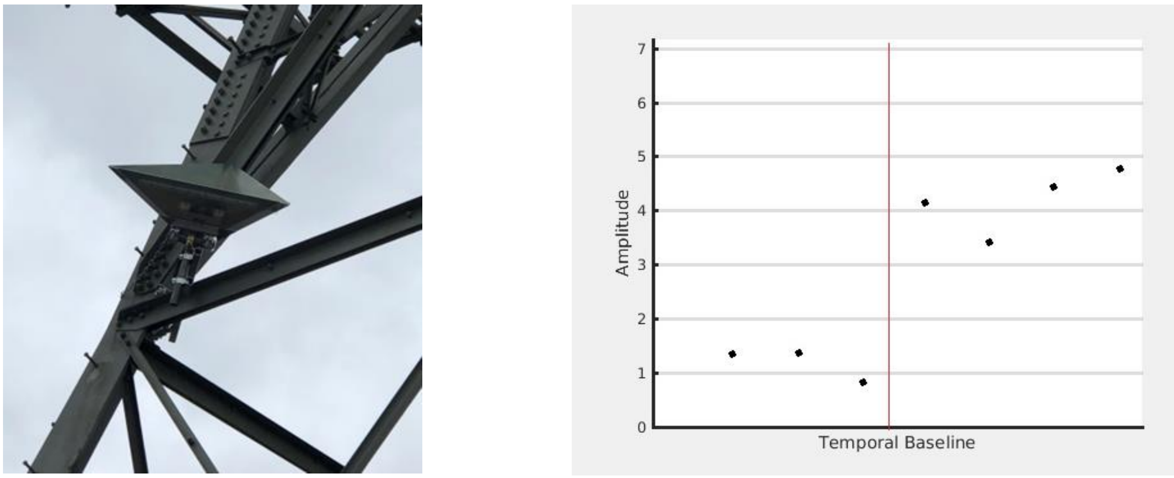


Fig.2 a) CR installed on Tower 1 at Deeside test site b) Amplitude time series before and after CR installation on Tower 1, the red line indicates the time of the CR installation

We plan to apply PSI analysis using SARPROZ software and Sentinlel-1 images (track 52) over the Deeside test side to investigate whether CR installation on the tower leads to select any PS pixel at the tower location. In the next phase of this study, we plan to improve the impact of the tower's CR experiments on the amplitude enhancement and phase stability using a new design. The radar cross-section (effectively the signal strength in the image) depends on the reflector size to the power 4, so increasing the side length to 1 m (relative to 70 cm) quadruples the cross-section. Reflectors larger than 1 m can be built, but they become increasingly difficult to manufacture to the required tolerances and more cumbersome to use operationally. Therefore, in our potential new design, we will assess how practical it would be to install a bigger CR or an array of small CRs on the tower.

Acknowledgments:

This project was an Alpha phase project led by National Grid Energy Transmission and funded through the Strategic Innovation Fund by Ofgem working in partnership with Innovate UK. The Strategic Innovation Fund (SIF) is designed to drive the innovation needed to transform UK gas and electricity networks for a low-carbon future.

References:

Cigna,F., et al. "25 years of satellite InSAR monitoring of ground instability and coastal geohazards in the archaeological site of Capo Colonna Italy" Proc. SPIE vol. 10003 pp. 100030Q Oct. 2016.

Ferretti,A., Prati,C., and Rocca,F., "Permanent scatterers in SAR interferometry," in IEEE Transactions on Geoscience and Remote Sensing, vol. 39, no. 1, pp. 8-20, Jan. 2001, doi: 10.1109/36.898661.

Kelevitz,K., Wright,T.W., Hooper,A.H., and Selvakumaran,S., “Novel Corner-Reflector Array Application in Essential Infrastructure Monitoring,” in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-18, 2022, Art no. 4708518, doi: 10.1109/TGRS.2022.3196699.

Perissin,D., Wang, Z., Wang, T., "The SARPROZ InSAR tool for urban subsidence/manmade structure stability monitoring in China", Proc. of ISRSE 2011, Sidney, Australia, 10-15 April 2011.