

## AIRBORNE REPEAT PASS INTERFEROMETRY FOR DEFORMATION MEASUREMENTS

**Jos GROOT, Matern OTTEN, Erik van HALSEMA**  
TNO Physics and Electronics Laboratory, The Netherlands  
[groot@fel.tno.nl](mailto:groot@fel.tno.nl), [otten@fel.tno.nl](mailto:otten@fel.tno.nl), [vanhalsema@fel.tno.nl](mailto:vanhalsema@fel.tno.nl)

**KEY WORDS:** SAR, Airborne Interferometry, RPI, Deformation, Dike

### ABSTRACT

In ground engineering the need for deformation measurements is urgent. SAR interferometry can be used to measure small (sub-wavelength) deformations. An experiment to investigate this for dike deformations was set up, using the C-band SAR system PHARUS (PHased ARray Universal SAR). This paper describes the progress made in the research.

### 1 MOTIVATION FOR THE EXPERIMENT

During extremely high floods a river dike can lose its stability, which can lead to catastrophic inundation of the polder to be protected. Loss of stability is warned for by increasing deformations. For an early warning system, which should support decisions to evacuate, input of actual information on deformations is essential. Only remote sensing techniques can supply such information in an efficient way. Repeat pass airborne SAR interferometry, which is capable of monitoring mm-level deformations, is the technique investigated in this experiment. The spaceborne equivalent was not investigated because of the unpredictability of floodings, and the high rate at which dikes deform during floodings.

### 2 EXPERIMENTAL CONSIDERATIONS

Accurate deformations can only be derived from high quality (highly coherent) interferograms. This puts stringent requirements on the orbit and beam directions. These are discussed in this chapter.

#### 2.1 Orbit and beam direction conditions

If the incidence angle of the two passes (for a single resolution element) differs too much, little or no coherence remains. If the absolute value of the perpendicular baseline  $B_{\perp}$  (directly related to the incidence angle difference) exceeds the critical (zero coherence) perpendicular baseline (Zebker and Villasenor, 1992), no coherence can be obtained. In our case the critical baseline is about 173 m.

The difference of the (horizontal) azimuthal beam directions of the two passes,  $\Delta\phi$  [deg], should fulfil a similar inequality. The coherence drops to zero if  $\Delta\phi$  exceeds  $1.9^{\circ}$  in our case (Geudtner, 1995).

Assuming a linear, multiplicative model we can write

$$\rho \approx \left( 1 - \frac{|B_{\perp}|}{173} \right) \left( 1 - \frac{|\Delta\phi|}{1.9} \right) \rho_r \quad (\text{for } 0 < |B_{\perp}| < 173, 0^{\circ} < |\Delta\phi| < 1.9^{\circ}; 0 \text{ otherwise}) \quad (1)$$

for the measured coherence of an object with real coherence  $\rho_r$ . If we allow for a coherence loss of at most 10 % due to baseline and 30 % due to azimuthal difference effects (totalling 37 % loss), we obtain the approximate conditions  $B_{\perp} < 20$  m and  $\Delta\phi < 0.6^{\circ}$ . For a single pass the aircraft position should therefore be within about 10 m of a planned flight track, while the beam azimuth should vary by less than  $0.3^{\circ}$ . The next section describes how this could be achieved.

## 2.2 Orbit and beam direction control.

Orbit control of PHARUS is normally done with a GPS (Global Positioning System) and (pressure) height sensors. In combination with the auto-pilot of the Citation this leads to orbit repeatability accuracies of up to hundreds of meters. This is not sufficient for interferometry. The 10 m condition was planned to be met by using the NLR developed PRS (Position Reference System, which includes an inertial reference system), of which the information was fed into the auto-pilot. The necessary input orbit accuracy for the PRS was estimated to be 1 m. To be able to meet the 10 m condition, the PRS had to be set to the code-tracking differential mode. This mode requires a ground-based reference station close to the operating area of the aircraft. The reference GPS data is sent to the aircraft by means of a telemetry uplink, where in real time an orbit is calculated with  $\approx 1$  m accuracy.

In order to fly the required flight track under all wind conditions, the attitude of the aircraft changes in response to the auto-pilot generated steering command. Therefore, to approach the  $0.3^\circ$  requirement antenna beam steering had to be used. The beam direction of the phased array antenna of PHARUS can be steered electronically in the slant range plane, in  $0.5^\circ$  steps. By using (in-flight available) orbit and attitude data it is possible to point the beam in the desired direction. For this experiment we implemented the so-called "geographical beam steering" mode: the beam is pointed (every second) in a specific horizontal direction (perpendicular to the ideal flight track), fixed with respect to the geographical north.

To aid off line processing (i.e., by providing a precise orbit to the SAR processor) a second GPS receiver was mounted in the aircraft. It provided a high precision ( $<10$  cm) flight track, sampled at 1 Hz.

## 3 THE EXPERIMENTS

A river dike near Gorinchem (The Netherlands) was selected as the main target of the measurements. (Fig.1).



Figure 1. River dike near Gorinchem. Bumpy road caused by deformations.

Eight corner reflectors (RCS 26.8 and 33.1 dBm<sup>2</sup>) were deployed to act as stable phase references. They were deployed at places on and close to the dike which were expected to deform, and some more stable places further away. The reflector positions and heights were levelled several times between the end of 1998 and the beginning of 2000. The levellings revealed a deformation rate of 1.2 cm per month at the end of 1998.

Two 8 km long flight lines were chosen, each at 6000 m height, but at different azimuth angles. This should enable one to not only measure the size of the deformation, but also the direction. The radar was operated with VV polarisation.

In 1998 two flights were performed to test the navigation. On 29 January 1999 and 3 February 2000 two measurement flights were carried out. In between some additional non-measurement test flights were performed. The 3 February flight benefited from the analysis of the preceding flights, and subsequent adjustments made to the radar and navigation systems.

#### 4 RESULTS

Figure 2 shows a detail of one of the SAR images obtained, containing the dike with the corner reflectors.

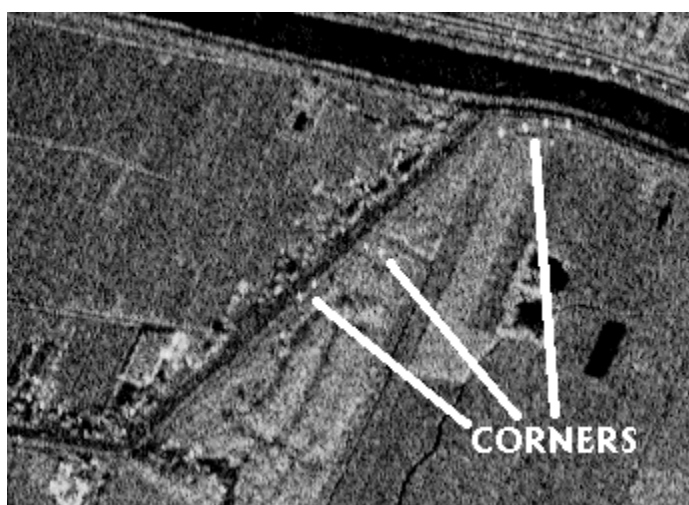


Figure 2. Detail of SAR image measured on 29-1-1999: dike with corner reflectors.

The resolution of the images is derived from the corner reflector responses as about 1.2 m (azimuth) and 5 m (slant range).

Figure 3 shows a typical example of the flight path (from the 10 cm accuracy data) of one of the runs of 29-1-1999. The 10 m horizontal distance criterion is clearly met. A remarkable feature is the oscillation, which is caused by the particular navigation implementation. The oscillation corresponds to about  $\pm 1.3^\circ$  azimuth angle variation, which is (partially) compensated by the antenna beam steering.

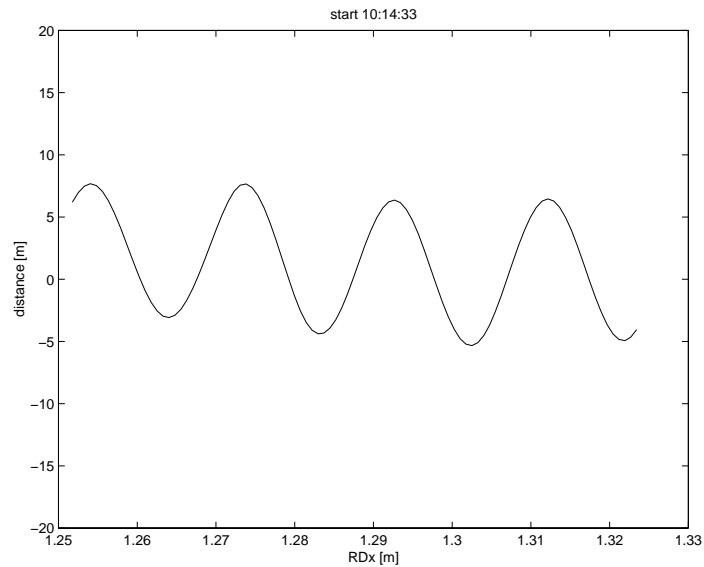


Figure 3. Horizontal distance to planned flight track as a function of RDx (~longitude).

Up till now we produced interferograms which exhibit coherences up to 0.7, but only in parts of the scene. This is possibly due to insufficiently compensated beam azimuth variations, to inaccurate orbit/attitude data, or to unknown processor faults. The next months will be used to locate the real cause, optimise the processing and/or the data acquisition.

#### ACKNOWLEDGEMENTS

The authors thank P.J.L. Blommaart, G.J. Husti, G.A.M. Kruse, D. van Loon, J. Samson, E.J.O. Schrama, A.J. Striegel and J.M.P.C.M. Visser for their cooperation in this experiment.

#### REFERENCES

- Geudtner, D., 1995. The interferometric processing of SAR data. Report ESA-TT1341, ESA.
- Van Rossum, W., Otten, M.P.G., Smith A., Groot J.S., 2000. The PHARUS system; an overview and recent developments. Paper number 157 in these proceedings.
- Zebker, H.A., Villasenor, J., 1992. Decorrelation in interferometric radar echoes. *IEEE Tr. on Geoscience and Remote Sensing*, 30(5), 950-959.