THE SETTLEMENT OF HONG KONG INTERNATIONAL AIRPORT BASED ON THE INTERFEROMETRIC POINT TARGET ANALYSIS

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ABSTRACT:

Hong Kong International Airport (HKIA) is one of the famous airports built by reclamation of the sea platform. However, the reclaimed area of the airport, which cost about $9 billion, has shown uneven displacement. Over the past two decades, researchers have used different methods to monitor the deformation of HKIA. As an emerging deformation monitoring technology, Interferometric synthetic aperture radar (InSAR), has been widely used to monitoring the deformation of HKIA in the last ten years. In this study, different from conventional interferometry, the target of this interference processing is single look complex (SLC) point data, which was extracted by points in the SLC data stacks (filtered by spectrum and backscatter intensity). We used 40 scenes of COSMO-SkyMed (CSK) SAR images to generate the differential interferogram point data. After multiple phase regression analysis, the SLC point data interferometric processing model can effectively eliminate baseline errors and atmospheric distortions, obtain highly reliable phase unwrapping results.

1. INTRODUCTION

Hong Kong International Airport (HKIA) is one of the busiest passenger and cargo airports in the world. It was constructed on two existing islands, namely Chek Lap Kok and Lam Chau, and land reclamation from the surrounding water (Uiterwijk, 1994) as shown in Figure 1.
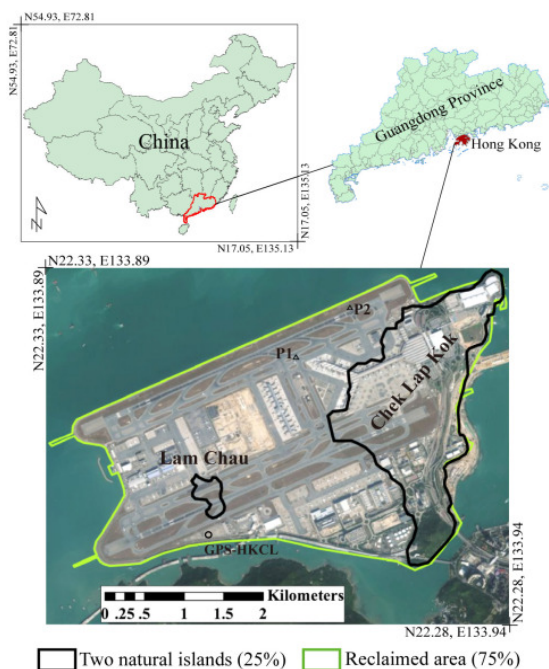

Figure 1. The location of HKIA.

Figure source: Wu et al. (2020).

The reclaimed land accounts for about 75% of the airport area. Reclaimed land usually undergoes long periods of settlement that may affect building structures and underground facilities such as water supply and sewage systems built on the land (Ding et al., 2004). Previous studies also demonstrated that in the reclaimed areas, the HKIA platform has been subject to severe settlement mainly due to soil consolidation (Uiterwijk, 1994; Plant et al., 1998; Plant and Oakervee, 1998; Tosen et al., 1998; Liu et al., 2001; Ding et al., 2004; Jiang and Lin, 2010). Therefore, there is an urgent demand to precisely monitor the progressive settlement of reclaimed land.

Most existing techniques for monitoring ground settlement rely on collection of data repeatedly at selected points, and then derive the magnitudes and rates of settlement from measurements carried out at different epochs. These point-based measurement methods are generally expensive and inefficient for monitoring large areas of settlement. Besides, sparsely distributed data points are often insufficient to provide information on very localized ground settlement (Ding et al., 2004). Interferometric Synthetic Aperture Radar (InSAR) has been illustrated as one of the most useful geodetic techniques for high-resolution large-area deformation measurements (Bamler and Hartl, 1998; Massonnet and Feigl, 1998; Rosen et al., 2000). Compared with deformation distribution on sparse points generated by ground-based geodetic methods (e.g., Global Positioning System (GPS) or spirit levelling), this technique can determine a two-dimensional (2-D) deformation field on a large scale and at a reasonable cost, obtained by computing the phase differences (interferograms) between Synthetic Aperture Radar (SAR) image pairs acquired at different times (Jiang et al., 2011). To overcome the limitations of the conventional differential InSAR technique, such as

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decorrelation and atmospheric artifacts, multi-temporal InSAR (MT-InSAR) techniques have been developed to retrieve high-accuracy time-series of deformation (e.g., Ferretti et al., 2000; Berardino et al., 2002; Hooper et al., 2004; Kampes, 2006; Pepe and Lanari, 2006; Zhang et al., 2012; Costantini et al., 2014; Jiang et al., 2014).

In this study, we attempt to monitor the displacement of the HKIA over the last two years using the space-borne SAR images, CSK (2019–2021), with the point selected and analysis, the settlement of HKIA can be generated.

2. STUDY AREA AND DATASETS

2.1 HKIA

The Hong Kong International Airport (HKIA) is a reclamation airport located on an artificial island north of Lantau Island, covering an area of 12.55 square kilometres. HKIA's platform is based on two existing islands, Chek Lap Kok and Lam Chau, with the remaining 75% of the area being built offshore through reclamation. The construction project was officially started in 1992, and it was officially completed and opened in 1998 after 6 years.

The construction was divided into two phases in total, marine and civil, and were carried out simultaneously at different periods in the reclamation works (Plant et al., 1998). Major projects in the marine include seawall construction, mud dredging and sea sand filling. Civil engineering involves blasting, excavation, filling, and geotechnical engineering.

2.2 Datasets

This experiment selected the satellite data of COSMO-SkyMed (CSK), from January 6, 2019, to November 30, 2021, a total of 41 descending images. The coverage area of the SAR dataset is shown in Figure. 2.

Figure 2. Areas of coverage of SAR images used in the study. The location of HKIA is in the red area.

3. METHODOLOGY AND RESULTS

3.1 Methodology

3.1.1 Interferometric processing: All SAR images in the experiment were processed by GAMMA software (Werner et al., 2000). The processing flow includes image registration, interference processing, terrain phase removal and coherence estimation.

3.1.2 Differential interferogram point data: The point interference processing is divided into four main parts, including the establishment of point list and SLC point data, differential interference processing, subsequent phase unwrapping and analysis (Rabus, B, 2004).

One of the key segments is generate point list. the point list can be generated by select the point scatter (PS) candidates from large SLC data stacks (>25) and small SLC data stacks. The way of selecting PS points is based on the intensity and spectral properties of the pixels, respectively. By merge the two list of PS point candidates, selected points are shown as Figure. 3.
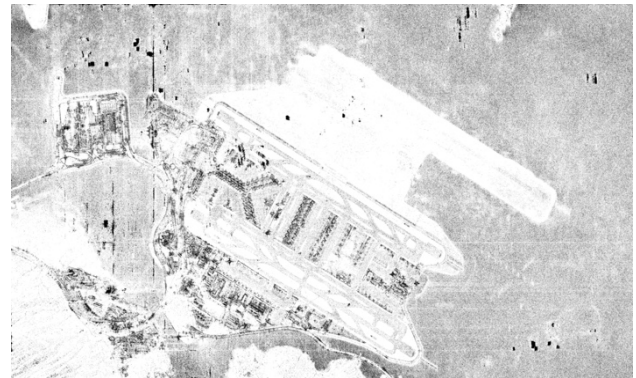
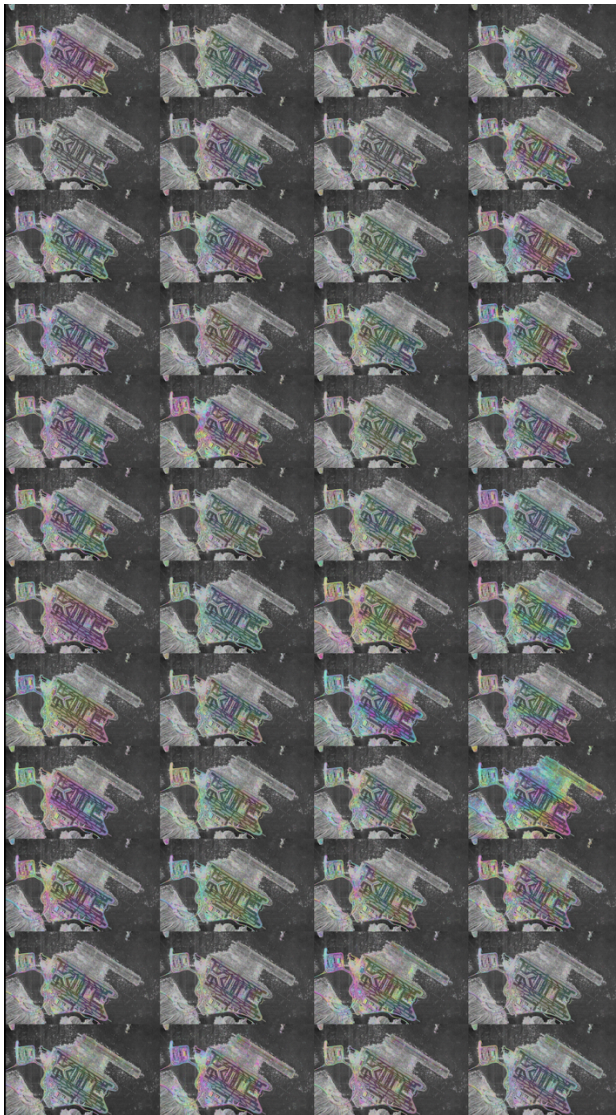**Figure 3**. Selected PS point candidates map.

The image pairs are shown as Figure.4. The longest time baseline is 140 days, with the max spatial baseline is 456 meters, totally 48 pairs.
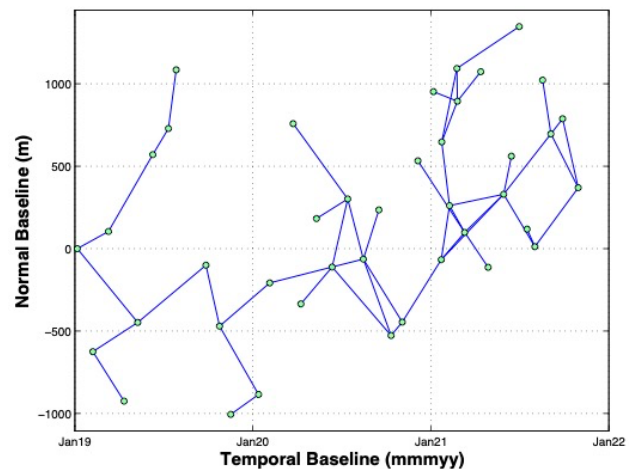
Figure 4. Acquisition dates and spatial baseline for image pairs.

48 interferograms are generated by after selected the SLC image pairs (Figure. 3), the result is shown as Figure. 5.

Figure 5. Interferograms of the PS candidate points.

3.1.3   Regression analysis for selected points: With the analysis of selected, the result of unwrapped phases will be more reliable.

Figure 6. shows the regression analysis for a pair of points. The location of the point is at the red circle on the map. Below two figures, the upper figure shows the 2D phase regression plot, with a small relative height correction. Lower figure plot the time dependence after compensation of the baseline dependence.
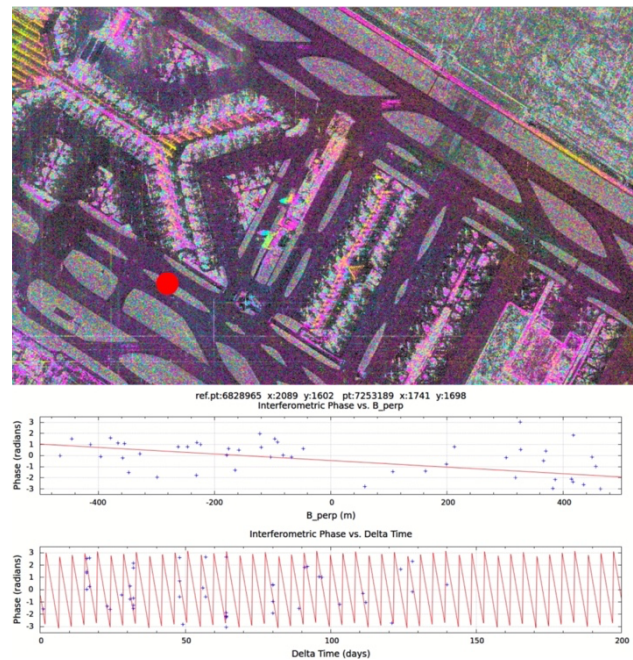
Figure 6. Regression analysis for a pair of points.

3.2   Result

After screening the quality of candidate points, the selected points are used for generating time-series result.
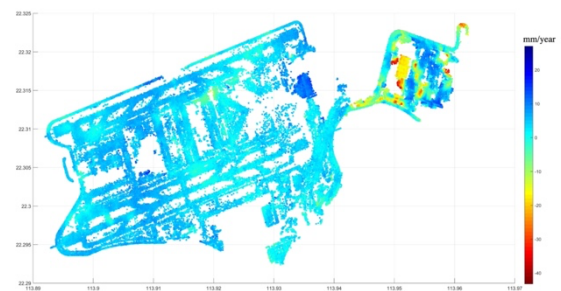
Figure 7. settlement velocity of the study area.

The displacement map (Figure. 7) shows the deformation rate during the observation period. The reference point is at the left lower conner of the HKIA study area. The map can be separated to the two parts. The left part is the HKIA area, while the right part is Hong Kong Boundary Crossing Facilities (HKP), Connected to each other by a road (Chek Lap Rd) reclaimed from the sea. HKP was began construction at Nov 2011 and finished at Oct 2018. Hence, there are obvious deformations displayed on this artificial island. The reason for the deformation is that the reclamation project has just been completed and the area is still in the compaction process of reclamation coating.

In this study, we focused on the displacement of HKIA. It can be seen from Figure 7 that the runway (113.92 e, 22.315 n) of the airport has an obvious deformation and settlement trend. This settlement has also been captured by many researchers (Wu et al., 2020).

4. DISCUSSION

Based on the reference point (refence point in Figure. 9) (113.895 e, 22.295 n), the maximum displacement of HKIA can reach 10.21mm/year in line of sight (LOS) direction, while the maximum displacement in HKP is 34.01mm/year in LOS direction.

Since all the construction and reclamation works of HKP were completed in 2018, it is normal for this area to have obvious settlement. The Los direction deformation process of the most obvious settlement area from the beginning of the observation period (2019 / 01) is shown in Figure 8. The location of this point is shown in Figure. 9, right red circle, P1.
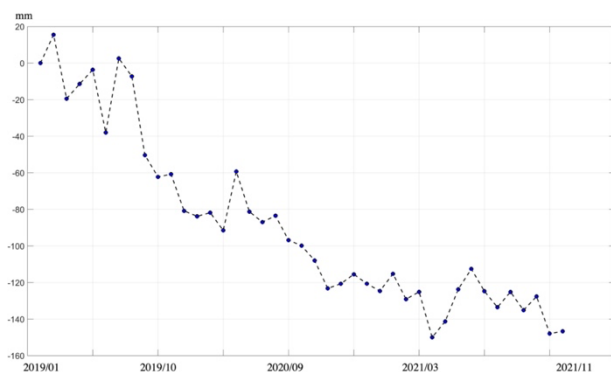

Figure 8. settlement of HKP.

Figure 9. Estimated overall settlement velocity over the two years.

HKP is in a trend of continuously accelerating settlement, and the sinking speed is the most obvious from May 2019 to May 2010. After a period of slow subsidence, accelerated subsidence began to occur in the HKP area.

At the left and upper circle in Figure. 9, P2, this location is the main deformation area of the Hong Kong International Airport. From the satellite image, this area is part of the runway of HKIA. The maximum settlement is almost 40mm during the observation period, based on the reference point.

The settlement of HKIA in the study are related to three main factors (Wu et al., 2020): the construction stage, the bottom alluvial sediment, and the landfill materials.

4.1.1 Construction stage: the construction stage might be the mean reason to cause the settlement on the southern runway. Figure. 10 shows the settlement on the runway, P2 in Figure. 9.
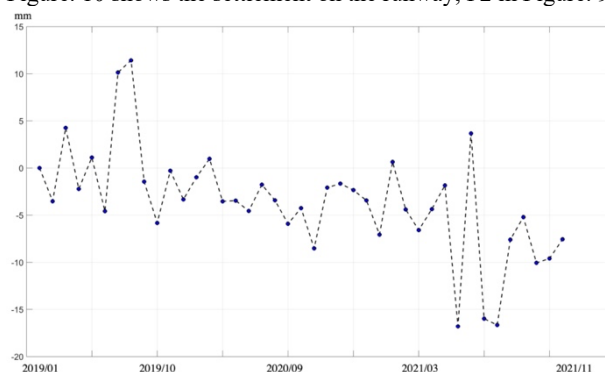

Figure 10. settlement in southern runway of HKIA.

In the prediction of Plant et.al (1998) and Tosen et.al (1998), there will be a settlement in the southern runway during the last two decades, especially in western end and the central section and eastern end. In this study, the maximum settlement of the southern runway is 6.64mm/year, the trend of settlement is gentler than the other two points.

4.1.2 Bottom alluvial sediment: The underlying alluvial deposits may have caused some subsidence at the west end and middle of the North runway (see Figure 9). According to plant et al., 1998, the underlying alluvial sediments in these two areas are the thickest. It was originally planned to carry out special treatment of sediments before the construction of the North runway to reduce settlement. However, as the northern runway needs to be constructed earlier than originally planned, the planned special ground treatment of the underlying alluvium is abandoned, which may lead to significant creep settlement in the area.

4.1.3 Landfill materials: The HKIA platform is filled with different landfill materials, i.e., type A-E, type A / B and mixed landfill (see Table 1). Jiang (2010) discussed the potential causes of the settlement of the South runway by analyzing the correlation between the measured settlement and the landfill materials.

Type	Material
Type A	Blasted rock with a maximum size of 2000 mm and a fine powder limit of 50%.
Type B	The maximum size of excavated soil or rock is 300 mm.
Type A/B	Mixture of type A and type B fillers
Type C	Sand fill with a fine content of 20% or less, usually wet, obtained from the ocean.
Type D	Seawall Rockfill
Type E	Blasting, sieving and/or crushing as required, up to 150 mm
Type F	Fully decomposed granite (CDG), with a maximum size limit of 200 mm

Table 1. Landfill materials for constructiing the HKIA platform (Plant et. al, 1998).

According to plant et al. (1998), the mixed filling material consists of material types A / B, B and C. Hence, it changes greatly in grading and compressibility. Therefore, the mixed filling material is likely to be the cause of significant settlement. Plant et al. (1998) in fact, it is suspected that the mixed filling material may lead to significant settlement.
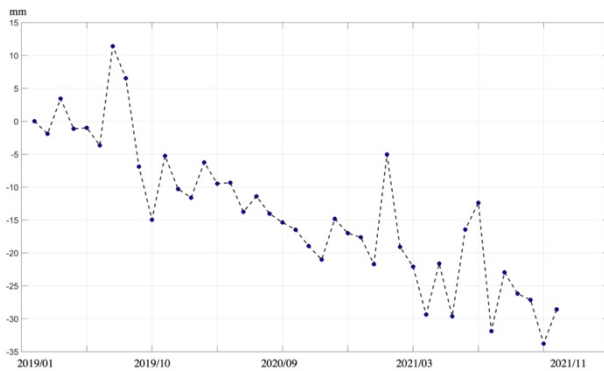
Figure 11. settlement in middle runway of HKIA.

Obviously, a settlement occurred in the middle runway of the HKIA platform, close to the Terminal 1 West Hall (P3 in Figure.9). The settlement in this area can reach 35mm in the past two years (see Figure. 11). The main cause of deformation in this area should be caused by reclamation materials. Meanwhile, it can be seen from satellite images that this area is close to the apron of terminal 1. This area needs to bear the pressure brought by the gravity of all aircraft when decelerating into the apron. Due to the impact of reclamation materials, this area has maintained a steady subsidence velocity (10.21mm/year) in the past two years.

5. CONCLUSIONS

In this study, we use the 41 senses of CSK satellite images to monitoring the Hong Kong International Airport based on the Interferometric point analysis. The results show the obvious deformation of HKIA. The results improve the model, including height, atmospheric phase, linear deformation rate and non-linear deformation history. Based on the selected PS point, the calculation can be improved.

The area in the Northwest middle runway has the most significant settlement, with a cumulative settlement of 40 mm through the observation period. The joint analysis of the measured settlement and geological data of the North runway shows for the first time that the settlement may be mainly related to the filler, alluvium and construction stage.

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