Abstract—The objective of this research was to map centimeter-scale soil movements on slopes that are prone to landslides. These small movements can be used as possible signs of an approaching larger landslide or rock fall. Two methods were used: an interferometric technique using TerraSAR-X data and a ground based technique with a theodolite and prisms. The study area - in a mountainous area - is characterized by high annual rain fall. TerraSAR-X is space-borne synthetic aperture radar operating in 3-cm wavelength. The TerraSAR-X dataset consisted of a sequence of 5 scenes. A soil movement of 1.55 cm was mapped with the interferometric technique in a broken nail-stabilized slope area. The corresponding movement (between 12 and 23 January 2009) by theodolite measurement was 2.65 cm. The interferometric technique measured the movement of a larger area while the theodolite measurement was a point measurement, which may explain part of the differences. More reliable theodolite measurements are preferred in areas with easy access while interferometric techniques can also be used in inaccessible areas.

Keywords—landslide, radar, ground monitoring.

I. INTRODUCTION

Slope instability represents landslides and other natural hazards threatening human activity especially in tropical countries as in Cameron Highland, Peninsular Malaysia. SAR interferometry (InSAR) using spaceborne data has been a very interesting technique in the domain of remote sensing. A typical application is the monitoring of ground displacement filed using SAR interferometric technique. Most landslides occurred in steep slopes where the instabilities of residual soil play a role [1]. Variation of rainfall intensity would strongly affect the distribution of pore water in the soil and influence the pattern of deformation as well as cracks. This could initiate excessive slope movements even if soil nails are used to increase the global stability [2].

ERS 1 and 2 tandem datas were used to produce DEM and glacier movement by generating interferogram to observe fringes in Himalaya [3]. Deformation maps of Cortenova landslides in Italian Alps provided by Ground Based SAR Interferometry are important for future assessment of the human being in landslide area [4].

II. STUDY AREA

The slope at KM26 in Gunung Pass area often occur landslide when the road was made and after the road already opened to the public at 2004 (Fig.1). To encounter that problem, the government had to make nail-stabilized slope mechanism and compacted soil with the concrete at the surface layer of the slope. Despite, landslides still occur in April and December 2007 and also April and December 2008 because of the rainfall reached the highest level. Monitoring of the slope movement is needed for the road user and the road itself. Ground measurement which measured by total station was used for measuring slope surface deformation with installed optical prisms or benchmarks on the dangerous and steep landslide. Huge fog and heavy rainfall are another difficulty to access the area.

The use of ground measurement and TerraSAR-X data were chosen because the landslide body area was too steep and dangerous to be accessed. In addition, it was impossible to install any traditional geotechnical instrument such as inclinometer and piezometer on that slope.

III. GEOLOGICAL DATA

Geology of the area along the highway of the study site is dominated by granite and schist. The schist varies in composition, from quartz-mica schist to mica-schist and graphitic schist. Geomorphology of the area is typically rugged tropical mountainous terrain and covered with dense tropical rainforest [5].

IV. SAR DATA PRODUCT

TerraSAR-X data sets from InfoTerra, Germany for Gunung Pass, Cameron Highland and surrounding areas were used for this research. Five images data could be used to generate 4 coherence images and 3 triherence images. These products were used for interferometry studies. The details regarding TerraSAR dataset used in this study are presented in Table 1.

DEM data used in this study was derived from Malaysian government. This data has a spatial resolution of 1m x 1m. The values are 16 bit signed integer and the DEM file is in raw format without any header.

High resolution satellite SAR image is required because of the study area in Gunung Pass site is limited in size.
TerraSAR-X which wavelength $\lambda = 3.10$ cm can provide the highest resolution within SAR sensors accessible to civilian users. Single polarization (HH) was used to acquisition mode. The incidence angle is 26.6º using ascending orbit. The first scene (12 January 2009) was selected as a master scene to which all other scenes were registered. Table 1 lists all scenes from Gunung Pass study site (From 12 January 2009 until 25 February 2009).

V. GROUND DATA

Surface slope movement was measured with theodolite and prisms mechanism. Six prisms mounted above landslide scarp area but the first prism was in the middle of landslide area it had gone before the satellite captured the image.

VI. SAR DATA PROCESSING

Synthetic aperture radar data for this study were processed by using the software developed by VTT, Research Centre of Finland. The raw data were processed by InfoTerra GmbH (Germany) to generate Single Look Complex (SLC) data product. TerraSAR-X SLC data were registered to generate coherence and triherence amplitude and coherence and triherence phase. Then these phases were flattened based on ellipsoid and topography to find out fingers on the study area.

Landslides require an accurate DEM because they occurred in areas of rough topography. Landslides usually degraded the ground surface quickly, eliminating interferometric coherence. Finally, landslides can deform the ground in excess of the high gradient limit [6].

VII. CONCLUSIONS

TerraSAR-X data of Gunung Pass site and surrounding area were processed for pre-landslide movement. Good coherence was observed over the sandy slope area which required of differential interferometry fringes. About 1.5 cm has been noticed in sandy slope area of Gunung Pass site. Even though in ground measurement with theodolite the movement of sandy slope is 2.6 cm. This difference maybe due to prism or benchmark (point of ground measurement is in a top of failure area and area of sandy slope is large). However it shows movement in sandy slope area from 2009-01-12 until 2009-01-23.

Radar data can be used in remote area which cannot be assessed by the user. The result of radar data may not be good because radar far away from the object and many factors can be included such as atmospheric effect, canopy, etc. But ground monitoring result might be accurate due to its directly measured from the ground. The disadvantages of this result are, it cannot assess in remote area, cannot cover large area, cannot record data from the past, etc. Monitoring landslide depend on geography and geology of field. Although the interferometry results obtained through TerraSAR data are not reasonable due to a variety of reasons.

ACKNOWLEDGEMENT

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REFERENCES

Figure 1. Study area located on Gunung Pass site. White color represent of number of prisms (no longer prism 1 on that point). XYZ is movement direction of prisms. Dotted-polygon is a nail loose of sandy slope. Dashed-polygon is next slope and still shows terraces of the slope.

<table>
<thead>
<tr>
<th>Scene</th>
<th>Date</th>
<th>Baseline (m)</th>
<th>No. of Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO_000008416_0009_1</td>
<td>12 January 2009</td>
<td>-51.04</td>
<td>11</td>
</tr>
<tr>
<td>SO_000008416_0010_1</td>
<td>23 January 2009</td>
<td>-90.48</td>
<td>11</td>
</tr>
<tr>
<td>SO_000008416_0003_1</td>
<td>02 February 2009</td>
<td>201.59</td>
<td>11</td>
</tr>
<tr>
<td>SO_000009187_0001_1</td>
<td>14 February 2009</td>
<td>-309.38</td>
<td>11</td>
</tr>
<tr>
<td>SO_000009187_0002_1</td>
<td>12 February 2009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table II. Prisms No. 3 movement data and interferometric technique on loose sandy slope based on cumulative rainfall data on that certain of day. Movement over than 10 cm can kill coherence and cannot detect from interferometric data. Time refer to theodolite reading to prisms.

<table>
<thead>
<tr>
<th>Date and time</th>
<th>Cumulative rainfall (mm)</th>
<th>Movement with theodolite (cm)</th>
<th>Movement with interferometric technique (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Jan 2009 14:37:00</td>
<td>2.2</td>
<td>2.648</td>
<td></td>
</tr>
<tr>
<td>23 Jan 2009 09:31:00</td>
<td>23 Jan 2009 09:31:00</td>
<td>63.4</td>
<td>0.523</td>
</tr>
<tr>
<td>03 Feb 2009 12:07:00</td>
<td>03 Feb 2009 12:07:00</td>
<td>83.6</td>
<td>0.877</td>
</tr>
<tr>
<td>14 Feb 2009 09:41:31</td>
<td>14 Feb 2009 09:41:31</td>
<td>108.4</td>
<td>0.422</td>
</tr>
<tr>
<td>25 Feb 2009 11:25:00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Dotted-polygon shows slope area with ground measurement (prisms no. 3) a. An amplitude image of slope study site in scenes with master image is 20090112 (red and blue) and scene 20090123 (green color); b. Ellipsoid flattening phase of coherence scene 20090112 and scene 20090123 which can determine slope height. With visual interpretation, dotted-polygon and dashed-polygon show 1.5 fringes and 0.5 fringes; c. Topographic flattening phase of coherence scene 20090112 and scene 20090123, with visual interpretation, 1 fringe shown in topographic flattened which means movement is $\lambda/2 = 1.55$ cm. TerraSAR-X data © InfoTerraGmbH (Germany) 2009.