Assessing Looting Holes by Using SAR Simulation

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Abstract

Looting is one of the biggest threats to archaeology and cultural heritage and archaeologists had been struggling with this problem for decades. Help to deal with this threat, we carried out an experiment in Wuhan / China and created our own artifical looting holes by digging two holes and shaping them in different measurements while collecting TerraSAR-X images from the experiment area. Our study aims creating simulated SAR images of looting holes, in the light of the information we obtained from our experiment. Parameters of collected SAR images and 3D models of the artificial holes will be foundation of the work with SAR simulation. Since field work is money and time consuming duty, simulating SAR images of looting hole is advantageous and benefitial since we can play with the 3D models and change their geometry. In this study we obtain SAR simulation images by using our 3D models of the looting holes. By using simulation, we are able to change the geometry of the hole and even possible to implement natural effects to the 3D model which is effective on results. Thus, assessment of the looting holes will become much more simple work and it will help to protection of cultural heritage.

1. INTRODUCTION

"Looting" is defined as the illegal excavating of historic locations, frequently by the creation of pits in places that have not yet been excavated by archaeologists (Tapete and Cigna, 2019). Looting results in the destruction of historical sites, loss of valuable artifacts, and disruption of archaeological research. It is driven by financial gain and can be linked to organized crime and armed conflict. Efforts to combat looting include using satellite imagery to monitor and detect illegal activities (Agapiou, 2020). The primary source of the illicit antiques trade is the looted archaeological objects, which are often confiscated, unrecorded, and sold in legitimate marketplaces. Archaeological discoveries are scarce resources, therefore once they are taken, they are lost forever (Proulx, 2013). The loss of archaeological artifacts is degradation or disappearance of cultural legacy. Certain elements of archaeology are considered to have "unique universal value" due to their exceptional characteristics, and as such, they require particular care and safeguarding (Hodder, 2010).

Figure 1. Examples of looting holes. (Google Images)

Worldwide, illicit excavations and looting of archeological sites put scientific study, cultural heritage, and the preservation of important historical data at serious risk. It is imperative that measures are taken to prevent looting and preserve archeological sites in order to preserve our common cultural legacy for future generations (Lasaponara et al., 2014). Its likely that illegal excavation activities carried out by local people who lives close by to that heritage site (Fig 1). It is also possible to see archaeological structures like blocks, stone carved inscriptions and even columns and sculpture parts used as wall piece in local people's houses.

Archaeologists typically utilize a technique known as direct survey, which is a method of archaeological research requiring measurement in direct touch on excavation areas. This kind of exploration is obviously not very precise and takes a long time (Pagounis et al., 2018). Recently, there has been a rise in interest in using satellite data to monitor archaeological sites. Research has demonstrated the value and utility of employing earth observation as a methodical technique for assessing the dangers associated with both natural and man-made features at archaeological sites, including regions that have been plundered (Agapiou, 2020). Developed techniques centered on Synthetic Aperture Radar (SAR) data are an effective way to identify and display alterations and damage on the surface of the earth (Yanan et al., 2016).

The use of remote sensing technology on historical sites is becoming more and more advantageous. When it comes to aerial imagery, UAVs (unmanned aerial vehicles) are not as capable of covering large regions as satellites. However, high resolution photographs obtained by satellites are able to reveal to archaeologists the nuances of cultural heritage sites that they can't observe or recognize from the ground. In this sense, satellite photos enable us to keep an eye on large regions, whereas UAV photos mostly concentrate on local tasks.

In the literature, there are succesfull studies with optical images, SAR images or combination of optical and SAR images. In the study of Tapete and Cigna (2021), study emphasizes the advantages of integrating radar and optical data for satellite-based archeological site monitoring. By leveraging the advantages of each data type optical data for detecting changes in vegetation cover and SAR data for accurate delineation of looting clusters, even in obscured areas this synergistic strategy enhances the identification of looting activities. By combining these databases, scientists are able to get a more thorough and precise understanding of archeological sites, which improves conservation efforts and safeguards against unauthorized activity. Another study from Agopiou (*2020),* researcher utilized Landsat 7 ETM+ images and a Random Forest classifier for supervised classification to detect looting at the Apamea

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archaeological site in Syria during 2011–2012. This approach achieved over 90% accuracy by training the classifier with specific areas of interest and applying a filter to reduce errors. Time-stamp change detection was also used to track spectral changes related to looting, demonstrating the effectiveness of Earth Observation techniques in monitoring looting activities.

Therefore, it is critical to observe cultural heritage sites systematically and precisely by using remote sensing to protect cultural heritage of the world. We used SAR simulation for better understanding of SAR images of looting holes in archaeological fields.

2. LOOTING EXPERIMENT AND SAR SIMULATION

2.1 Looting Experiment

It has already been demonstrated that widespread looting activities can be identified in high resolution SAR photos, as in the case of the Syrian civil war. (Tapete and Cigna, 2016). So-called industrial scale looting activities including digging with heavy construction vehicles like excavators leave big marks/holes on the ground which sometimes reaches to 10 meters width. When it comes to small-scale looting holes comparing to industrial/organized looting, it is much harder to detect the holes because of their small sizes, down to 1 meter. In the study of Tapete and Cigna, its been shown usage of Optical and SAR imagery to detect looting holes and study clearly shows how low is the number of SAR imagery studies on this subject (Tapete and Cigna, 2019).

In this experiment, we dug 2 artificial looting holes (Fig 2.), giving them different measurements in different times to collect before and after SAR images of artificial looting holes in our study area to understand the possibility of detecting small-scale looting holes.

Figure 2. First two holes with 1x1 (left) m and 2x1 m (right) size.

After digging two looting holes in experiment area (Fig. 3), we start collection after images. TerraSAR-X ST and HS images have been used in this study to collect high resolution images in order to make assesing of the holes easier.

Figure 3. Experiment area and the location of the holes.

After we dug 2 holes, we left the 1st (1 meter depth, 1 meter width) hole as it is and over time, we changed the measurements of the 2nd hole from 2x1 (2 meter depth, 1 meter width) to 2x2 (2 meter depth, 2 meter width) and 1.2x3 (1.2 meter depth, 3 meter width) at the end (Fig. 4). We obtain TerraSAR-X images in different parameters by changing the orbit, polarization, angles to have a different view on the holes. We also realize that position of the soil waste standing besides the hole is effecting the result depends on the orbit.

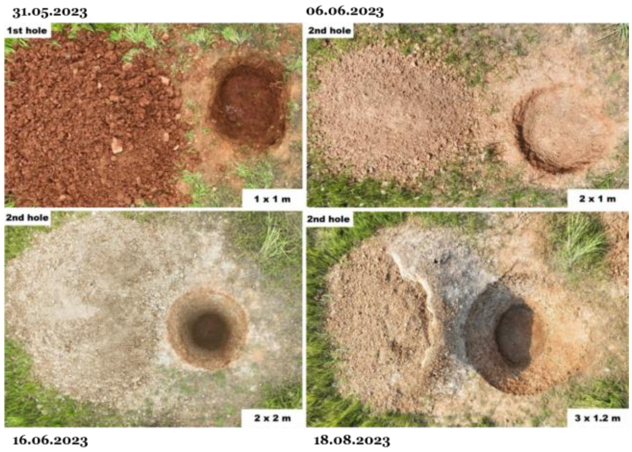

Figure 4. Artificial looting holes in different sizes.

After collection all TerraSAR-X images, we were able to detect the holes, mostly the 2nd hole. While the 2nd hole was more visible, we only detected 1st hole in only one image clearly out of 18 “after” images (Fig. 5)

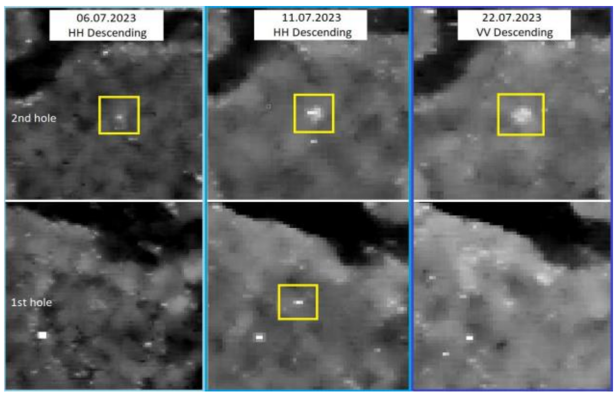

Figure 5. Examples of best results of the experiment.

Experiment carried out in flat surface without the general effects of the heritage sites (vegetation, slope, rocky areas, flood etc.). With that reason, we tried two different effect on the 2nd hole to see how natural effects would change the results.

Heavy rainfall in June showed us a good example of natural effect on looting holes. While we could detect it with these parameters under normal conditions, in the image taken in June 19 after heavy rainfall (while 2nd hole was filled with water), we were not able to detect any reflection from the hole (Fig 6).

Figure 6. Result after rainfall. 2nd hole filled with water (left) and TerraSAR-X image result (right)

Another test was completely covering the 2nd hole with camouflage to give leaf/vegetation effect. In the obtained TerraSAR-X image, we realized that it was possible to see reflection from the 2nd hole even when its totally covered with artificial leaf camouflage (Fig 7).

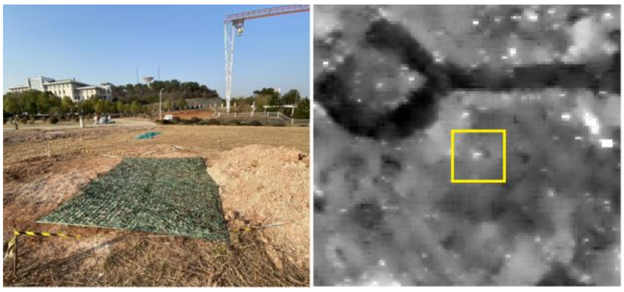

Figure 7. 2nd hole covered with comuflage (left) and TerraSAR-X image result (right)

Overall, experiment showed that detecting small-scale looting holes with very high resolution SAR images is technically possible. Since looting holes are not always in the flat and open surface, there are also limitations like geographical conditions, natural effects, archaeological structures etc.

2.2 3D Models

Carrying out "Looting Experiment" didn't just gave us information about importance of the parameters, natural effects and measurements of detecting the small-scale looting holes, but also we created 3D photogrammetric models of the holes to use in simulating SAR images.

We have created 3 different 3D models of 1st hole with 1x1 meter, 2nd hole with 2x2 meter and 2nd hole with 3x1.2 meter measurements (Fig. 8).

When it comes to SAR simulation, the quality and geometry of 3D models are important to get a good Ray-tracing result (Fig. 9) . A computer graphics technique called ray tracing mimics the way light interacts with virtual objects to produce lifelike visuals that have reflections, refractions and shadows. Because it makes use of space optimization, antialiasing, and shading algorithms to improve visual quality, it's a potent tool for creating realistic computer-generated environments (Kuchkuda, 1988). Ray tracing simulations accurately represent the scattering effects of man-made objects, improving our comprehension of high-resolution SAR images. By generating synthetic reflectivity maps, this technique makes it possible to analyze intricate scattering mechanisms and compare the results with actual SAR images. Researchers may forecast reflectivity patterns and obtain important insights for analyzing SAR data by tracing rays across the model space and storing signals with various reflection levels. This will ultimately improve the processing of high-resolution SAR images (Auer et al., 2010).

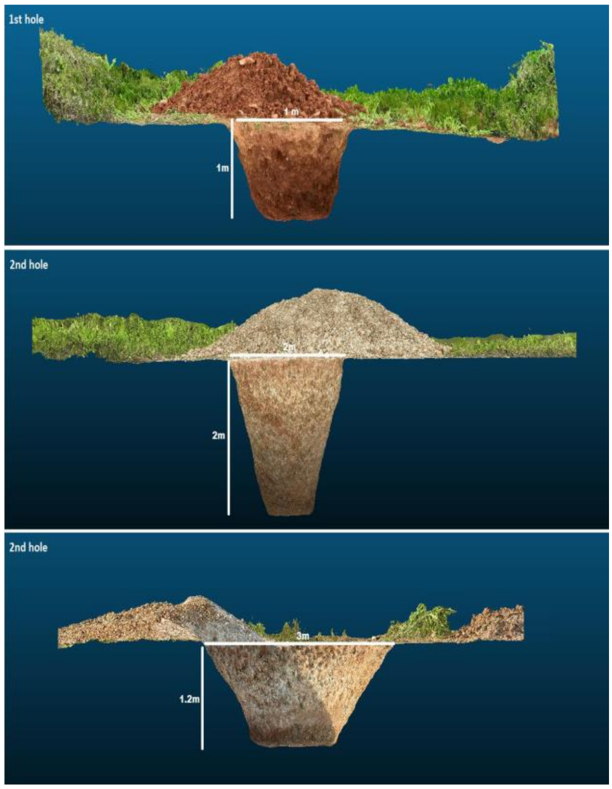

Figure 8. Side view of 3D photogrammetric models

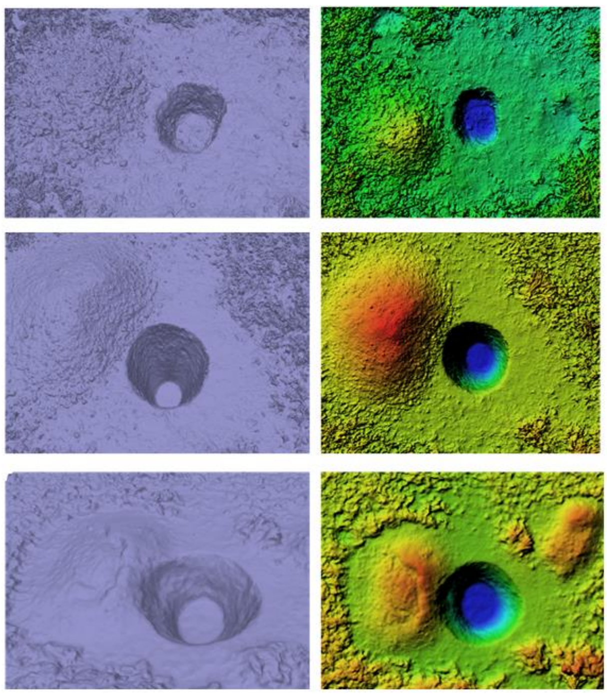

Figure 9. 3D models of the looting holes with the high detailed geometry. Top down : hole 1 and two versions of hole 2 (Solid model without texture on left, DEM on right side)

3D models allow us to change, rotate and add new features to them before we use them in SAR simulation. For instance, in the section 2.1. we talked about the importance of the location of soil waste beside the artificial looting holes (Fig 10). In SAR simulation, we can rotate the 3D model easily and change the location of the soil waste and obtain different results.

Figure 10. Soil waste beside the artifical looting hole (3D model)

2.3 SAR Simulation

In the section 2.1. we mentioned how rare are the studies on the subject of detecting looting holes with SAR. In some cases, optical images are not beneficial since there are some strong side effects like cloudiness. Since SAR is weather free, (except heavy rain) it is beneficial to use in this task or combine it together with optical images.

The problem about working with SAR images is that there is no archieve of very high resolution SAR images to use in the subject of looting detection. Beside that, it can be expensive to collect and to archieve very hight resolution SAR images. For this task, SAR simulation is a great tool. Simulating SAR images is one of the essential tools for assisting with the analysis of collected SAR data (Balz, 2007).

There are different approaches to obtain SAR simulation in the literature. Study of Balz and Haala (2003), in order to compare simulated SAR images with actual SAR photos, they create SAR simulations based on 3D city models. This procedure improves operator training and SAR picture interpretation abilities in intricate urban settings while supporting change detection and partially automated building reconstruction. In another study of Balz And Stilla (2009), real-time synthetic aperture radar (SAR) simulation was conducted using a hybrid graphics processing unit (GPU)-based method. The system combines a novel image-based GPU ray-tracing method for monostatic SAR double-bounce simulation with rasterization for real-time single-bounce simulation. This method balances speed and precision in SAR simulation, enabling quick simulation results even in intricate and expansive situations. Tao et al. (2011), by offering geocoded, simulated optical and SAR images that are directly comparable to actual SAR photos, the approach described in the study aids in the interpretation of SAR images in urban settings. This makes it easier to comprehend urban landscapes acquired in Synthetic Aperture Radar (SAR) photos by rapidly detecting objects in the images and separating overlapping reflections. Another study on SAR simulation using simulated images produced based on RaySAR and digital surface models, proposes a novel method for automatic interpretation of SAR images in urban locations. The system generates different image layers (layover, shadow, double bounce, ground) for specific structures while taking surrounding influences into account in order to facilitate object recognition in complex urban environments. The method demonstrated accurate building layover contours and good geocoding accuracy when evaluated in central Munich using LiDAR data and compared with TerraSAR-X images (Tao et al, 2013). To enhance geo-referencing and automate change detection in urban settings, Balz (2014) used SAR simulation in conjunction with 3D-city models. The approach effectively detects changes by comparing generated SAR images to real data. SAR simulation is still useful in urban settings for time-sensitive applications, even with obstacles like occlusions. In another study, in order to improve the fidelity of focused images for a better understanding of material properties and target interactions, the full-wave technique in SAR imaging simulation accurately represents electromagnetic interactions among objects. This technique improves radar target simulation for sophisticated SAR technology system design and algorithm development (Ku et al., 2018).

To produce accurate and efficient simulation of complex 3D scenes, ray tracing technique from computer graphics is utilized to simulate SAR images (Meng et al., 2020). David Kirk Buck developed POV-Ray in the mid-1980s for the Amiga. In 1989, it changed to become POV-Ray, which is renowned for creating realistic images. Since then, a group of volunteers have worked tirelessly to develop the program, which is still a well-liked raytracing tool in the computer graphics industry (Buck, 2001). For SAR image simulation, POV-Ray (Persistence of Vision Ray) has several benefits: it is freeware, well-tested, adaptable, and designed for effective ray tracing. Nevertheless, some of the drawbacks are that improvements must be made continuously and that geometric correctness takes precedence over radiometric accuracy. Speckle is also not included (Auer et al., 2008).

In this work, we used our looting experiment results (TerraSAR-X images, Metadata informations, 3D models) as a base data and shape the simulation parameters around it to obtain SAR simulation images. We also created new virtual model by filling the 2nd hole with water in a different level. Beside that we rotate our models and used different parameters to obtain new angle and look in SAR simulation. By previously working in this topic Auer et al. (2016) developed RaySAR SAR simulator and the primary objective was to examine the properties of scatterers in SAR images that are associated with remarkable and persistent signatures through time, and RaySAR have been publicly available to the SAR society since 2016. We carried out this study with RaySAR SAR simulation tool in order to acquire simulated SAR images of the looting hole images with varying angles and looking directions to have better understanding on SAR images. With a standard office computer and ray-traced 3D models and sensor data, RaySAR is an incredible tool that can produce SAR simulation images in a matter of minutes.

3. RESULTS

In this section the generated SAR simulation results are shown and discussed in the frame of assessment on SAR images. We tried to show 2 artificial looting holes simulation results, side by side with high and low resolution in the sense of understanding the results by observing them together. We choose and mainly focused on 2nd looting hole to show different angles and how can we change the 3D models to show natural effects (rainfall). Main point of this study was understanding how RaySAR is working on looting holes since they have complex, diverse and asymmetrical geometry. We mostly used same azimuth and slant range pixel spacing to obtain easy-to-read geometry. Below we show the results of looting hole number 2 and 3.

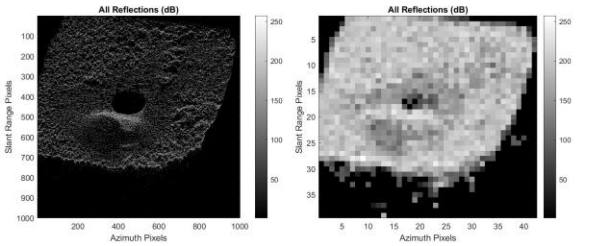

Figure 11. 2nd looting hole with 2x1 meter. (left : azimuth pixel : 0.01, range pixel : 0.01, right : azimuth pixel : 0.26, range pixel :0.26)

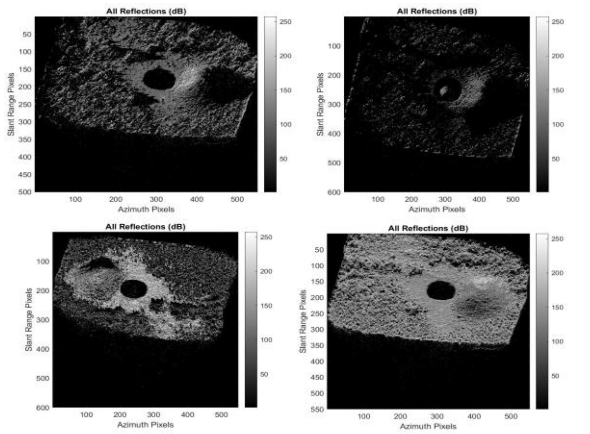

Figure 12. 2nd looting hole with 2x1 meter. Results of different sensor positions and different looking angles. (azimuth pixel : 0.01, range pixel :0.01)

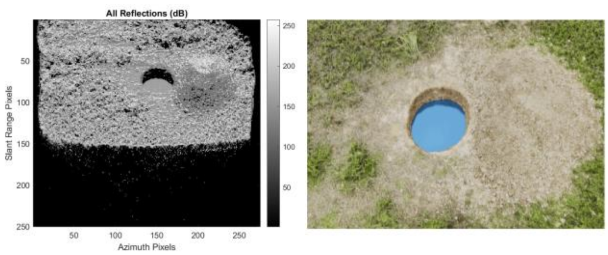

Figure 13. 2nd looting hole with 2x1 meter. (left : sar image, azimuth pixel : 0.01, range pixel :0.01, right : 3D model where we filled the hole with model to mimic water)

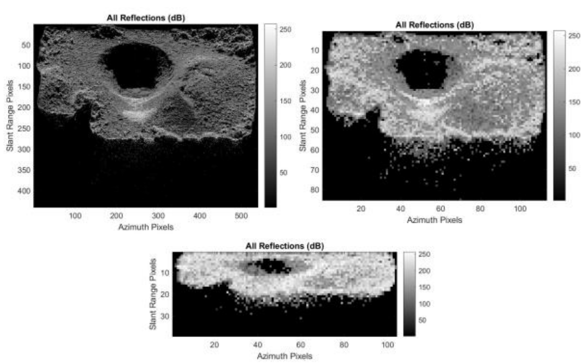

Figure 14. 2nd looting hole with 1.2x3 meter. (top left : azimuth pixel : 0.01, range pixel :0.01, top right : azimuth pixel : 0.26, range pixel :0.26, bottom : azimuth pixel : 0.26, range pixel :0.60)

When we focus on hole and soil waste, as results shown, in figure 11 and 12, the looting holes are mostly shown with black pixels and we usually receive most of the bright pixels from soil waste standing beside the hole. Figure 14 shows the results of 2nd hole with 1.2x3 measurement where we can see backscatter from the side walls of the hole due to its wide width and more inclined walls than other steep pits.

In figure 13, we showed how we changed the 3D model to show the benefits of SAR simulation. We were able to fill the hole with water by using Blender software, mimicking the rainfall. As we expected, it gave us similar reflection as the soil surface around the hole, like we showed before with figure 6 in section 2.1.

4. CONCLUSION

The results we generated showed us how practical and beneficial SAR simulation is to work on looting holes. The ability of editing the 3D model however we want is a great opportunity to create different scenarios of archaeological areas. In the literature, many SAR simulation studies focused on urban areas and buildings in general. Since small-scale looting holes have their own complex, mostly circular geometries, SAR simulation on looting holes should be mastered by working on all kind of measurements and natural effects to achieve better results. Because lack of the very high resolution SAR image archieves, in future studies we should focus on creating big dataset of it by using SAR simulations to create our own training images for machine learning studies. By doing that, it may give us opportunity to detect looting holes by using change detection algorithms, systematically.

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