Screening of Earthen Levees using TerraSAR-X Radar Imagery

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Abstract— This paper presents early results of applying the TerraSAR-X multi-polarized data to the task of identifying problems on earthen levees. This application could save levee managers much time and expense in monitoring levees by prioritizing them according to urgency for closer inspection and analysis. One particular sign of potential impending levee failure is the appearance of a slough slide. Early detection of these from a remote sensing approach could save time versus direct inspection. Furthermore, the potential to use the SAR data to identify soil properties that could lead to future slides is being investigated. We are applying a number of classification algorithms to this problem, including Shannon entropy based classification and texture analysis using wavelet decomposition. Furthermore, a multi-temporal approach using imagery from successive orbits in a change-detection application shows promise in responding to changes in vegetation that correlate with the presence of a slide. The study area is a section of the lower Mississippi River valley in the southern USA, where earthen flood control levees are maintained by the US Army Corps of Engineers. Early results are promising, although additional data is needed for better assessment of the results.

I. INTRODUCTION

Earthen levees protect large areas of populated and cultivated land in the US from flooding. The potential loss of life and property associated with the catastrophic failure of levees can be extremely large. Over the entire US, there are more than 150,000 kilometers of levee structures of varying designs and conditions. There is a growing need to prioritize the monitoring of the network of dam and levee structures. Levee managers and federal agencies need to assess levee health rapidly with robust techniques that identify, classify and prioritize levee vulnerabilities with lower costs than traditional soil-boring programs, which can cost millions of dollars and provide information about the subsurface only in the immediate vicinity of a small-diameter borehole.

In this paper, we present early results of ongoing research involving the study of using Synthetic Aperture Radar (SAR) imagery along with other remotely sensed and in-situ data for wide area risk mapping of the Mississippi river levee system. Results using TerraSAR-X imagery collected over a part of the study area for 3 dates are presented. The images were collected in VV StripMap mode on August 24th, 2010 and in dual polarized (VV/HH) SpotLight (SL) mode on September 4, 2010 and High Resolution SpotLight (HS) mode on September 26, 2010. The key parameters of the TerraSAR-X are given in Table 1 [1].

Our test study area is a stretch of 230 km of levees along the lower Mississippi River along the western boundary of the state of Mississippi. Two types of problems that occur along these levees which can be precursors to complete failure during a high water event are slough slides and sand boils. Sand boils are springs that form on the land side of a levee containing a river at extremely high flood stage. Hydrostatic pressure generated by the column of river water exerts a downward force that is too great for the wall material of the river channel to contain, and thus water is forced through the wall material of the channel [2]. Slough slides are slope failures along a levee, which leave areas of the levee vulnerable to seepage and failure during high water events. An illustration of slides and sand boils is shown in Figure 1 [3]. The roughness and related textural characteristics of the soil in a slide affect the amount and pattern of radar backscatter. The type of vegetation that grows in a slide area differs from the surrounding levee vegetation, which can also be utilized in detecting slides [4].

TABLE I
TERRASAR-X PARAMATERS

Parameter	**Value**
Radar Carrier Frequency	9.65 GHz
Range Bandwidth	150 MHz
Radiated RF Peak Power	2 kW
Polarization	HH, HV, VH, VV
Incidence Angle Range	20° - 45° full performance
Nominal Orbit Height at the Equator	514 km
Revisit time	11 days
Inclination	97.44°
Pulse Repetition Frequency	2.0 kHz – 6.5 kHz

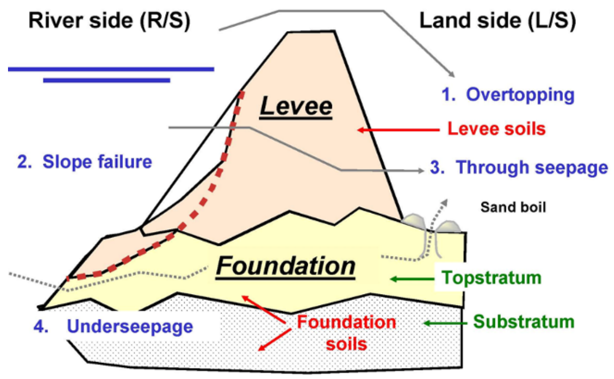


Figure 1: Illustration of levee failure mechanisms, including slough slides and sand boils.

Early detection of the occurrence of these events can assist levee mangers in prioritizing their inspection and repair efforts. A remote sensing based solution for their rapid detection would be more efficient and cost effective than frequent on site visits. Furthermore, it may be possible to detect less obvious precursors to the slides and boils themselves by sensing characteristics of the surface soils and vegetation. A working hypothesis of this study is that such characteristics will be manifested in the backscatter of polarimetric radar due to its response to spatially variant soil moisture.

II. Spaceborne X-Band SAR Data

In this paper, data from the German TerraSAR-X satellite was acquired over portions of the study area as shown in Figure 2. This data has spatial resolution on the order of one meter, but is only available at X-band. However the easy availability of repeat intervals with which it can be acquired, (compared to airborne instruments), is a factor in why we study the potential benefits of this data for our mapping task.

Ancillary data can be used in conjunction with SAR backscatter data to assist the levee classification process. Such data could include knowledge of the soil characteristics in the vicinity of the levees, the underlying geology of the area, and history of past problems and inspections of the levees. In ongoing work, we are studying the benefit of combining such features with features derived from the SAR backscatter in an attempt to improve the classification accuracy of the system. Another approach one can use in exploiting such ancillary data is to have different classifiers trained and optimized separately for SAR features extracted from regions with different geological properties (e.g., soil types). Once the training of such a system is complete, information from ancillary data can be used to invoke the "appropriate" classifier (tuned and optimized using data with similar geological properties). The assumption with this latter approach is that the levees can be partitioned into a finite (and manageable) number of discrete regions, each with similar underlying geological properties. We also plan to implement and study the performance of this second approach in our studies.

III. Classification Methodologies

A. Entropy based Feature Extraction

TerraSAR-X Single Look Slant Range – Complex (SSC) spotlight dual-polarization data was used to compute a 2x2 Covariance [C2] matrix. This covariance matrix is an incoherent polarimetric representation relating to second order statistics of the partial polarimetric scattering matrix elements [5]. The H/A/Alpha Decomposition [6] is based on an eigenvector decomposition of the (2x2) complex Covariance [C2] matrix. The Entropy (H) indicates the degree of statistical disorder of the scattering phenomenon. The Shannon Entropy (SE) is a sum of SE_I and SE_P, where SE_I is the intensity contribution that depends on the total backscatter power and SE_P the polarimetric contribution that depends on the degree of polarization [7]. Figure 3 represents preliminary results of such a feature extraction. The slide areas exhibit high entropy (red) whereas the healthy levee areas show low entropy values (blue). This processing was performed using the PolSARpro software [8] from the European Space Agency. SE may be a useful feature for discriminating active levee slides, as shown in the result.

B. Wavelet based Texture Feature Extraction

Wavelet features were computed within a 7x7 spatial window using Daubechies wavelet algorithm [9]. These features along with the window means and variance and HH and VV backscatter magnitude were used to create a 35-dimensional feature vector for each pixel. A Maximum Likelihood classier was employed for the two-class problem of detecting slide areas versus healthy levee areas. Initial tests used 3 slides for training, while testing on the fourth slide. One such result is shown in Figure 4, obtaining 67% accuracy. Blue pixels represent the class "slide". Green areas are healthy levee class and the polygons show the test masks; the smaller one near the center is the actual slide area.

C. Multitemporal Classification

A multi-temporal classification was performed using 3 successive VV and HH scene acquisitions from August and September 2010. This time series was classified using the ISODATA unsupervised clustering algorithm. Identified clusters were then grouped and labeled based on field and aerial photo observations. Figure 5 illustrates outcomes from this experiment. Changes between the dates are due mainly to vegetation, so the classifier is identifying differences in rates of growth, which likely reflect different plant species and/or age. Field observations detected different types of weeds growing within slide areas not present outside of them. The high biomass classes, when found on the levee slopes, appear to correlate well with active slide location in this limited test area.

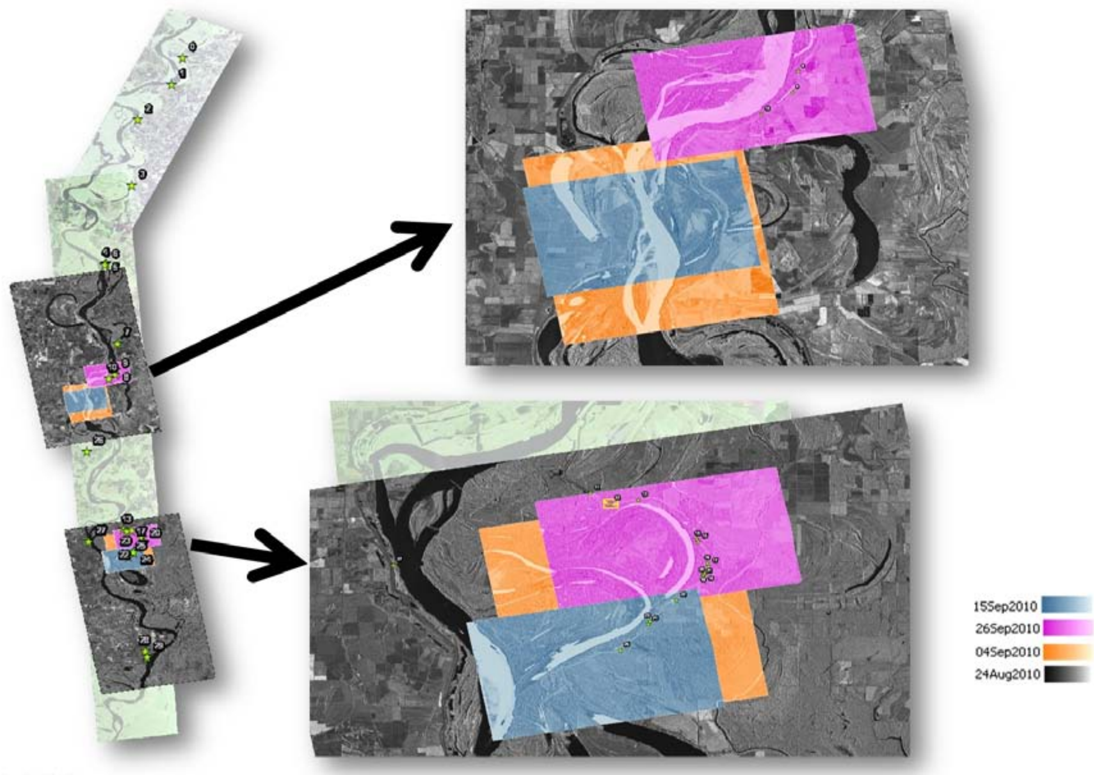


Figure 2: TerraSAR-X radar backscatter in both HH and VV polarizations were acquired on four successive cycles in 2010. The overall project study area covers 130 km of the Mississippi river valley along the western border of the state of Mississippi.

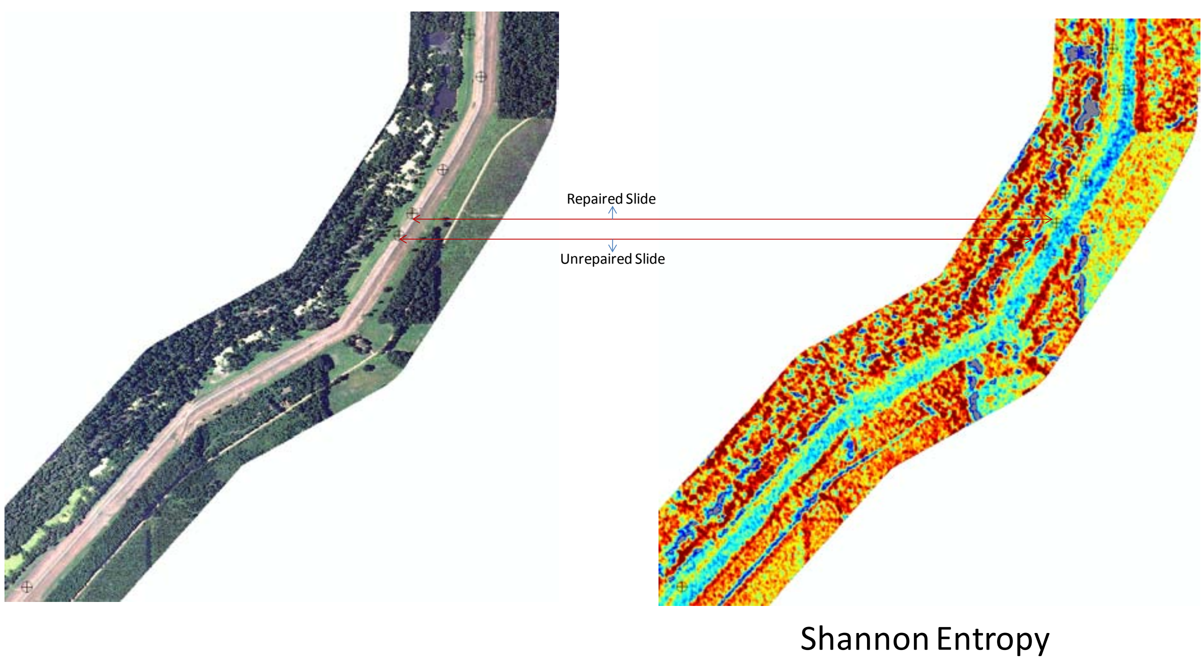
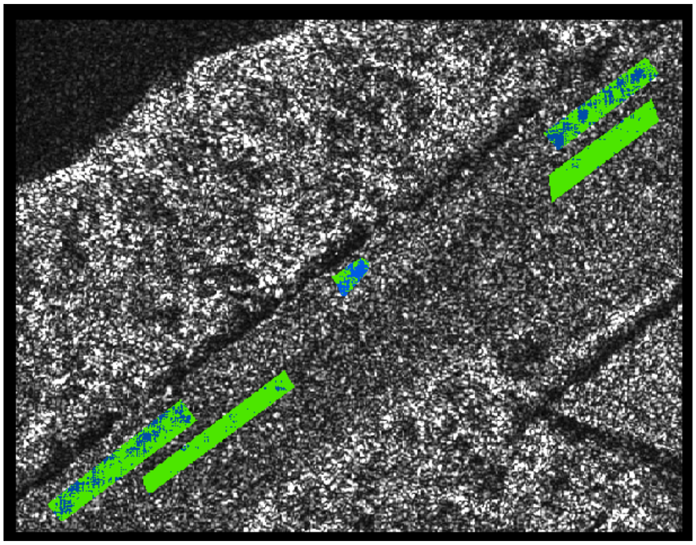


Figure 3: *Illustrating the Shannon Entropy feature over a section of the Mississippi Levee system. High spatial resolution optical image (left) and Shannon Entropy (right). Notice the slides (repaired and unrepaired) show up as anomalies when visualizing the entropy feature within the levee area.*



FEATURES USED
HH Backscatter magnitude
VV Backscatter magnitude
VV/HH ratio
HH Mean
VV Mean
HH Variance
VV Variance
<u>Wavelet Features</u>:
approximate coefficient plus horizontal, vertical, and diagonal detail coefficients means and variances (14 features each for HH and VV)

Figure 4: Illustrating the SAR imagery from the levee area, the classification results and test areas (blue: detected landslide, green: test area masks), and the features used for this classification task. The overall accuracy for this particular experiment was 67%.

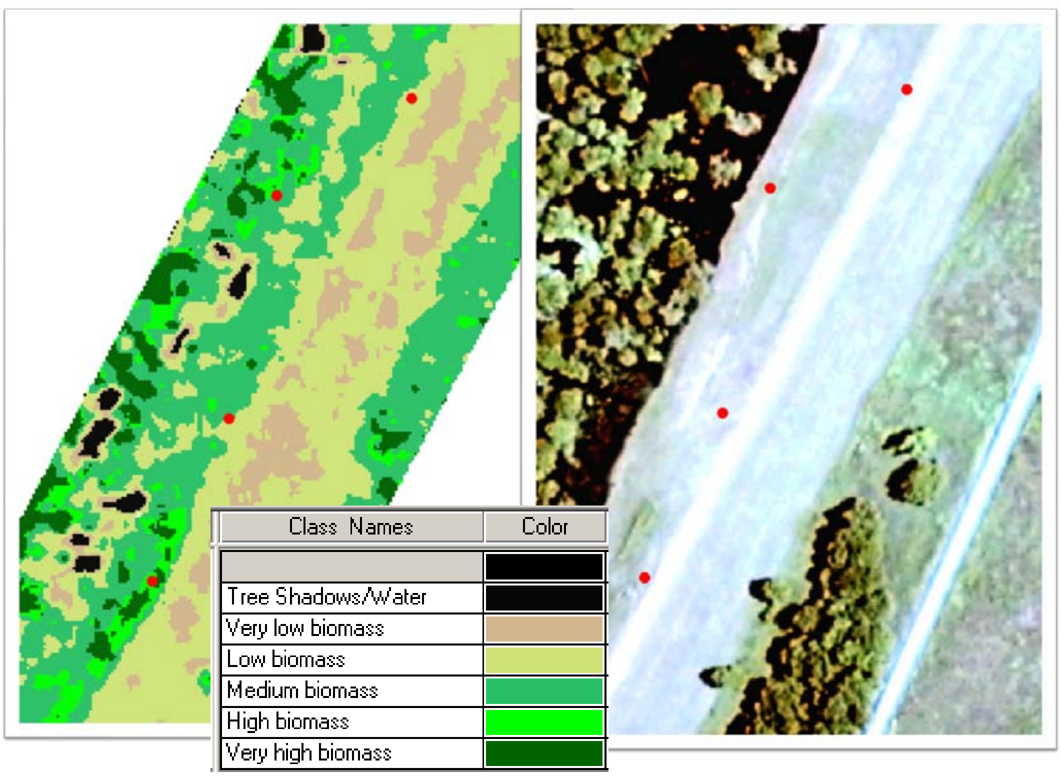


Figure 5: Illustrating the results from the multi-temporal classification.

IV. CONCLUSIONS AND FUTURE WORK

The results shown in this paper are preliminary results of studies investigating the potential of space-based multi-polarized Synthetic Aperture Radar for classification and analysis of earthen levees. Potential problem areas along the levees such as through-seepage, sand boils and slough slides may be detectable using this data, due to their effect on surface roughness and scattering mechanism. This paper focused on the detection of slough slides using TerraSAR-X satellite-based on X-band SAR. Several classification methods were tested on a small sample of levees with active slides. Polsar covariance decomposition methods show promise, as evidenced by good correlation between high Shannon Entropy values and active slide locations. Texture-based features that use statistics of windows around each pixel also show promise as evidenced by the wavelet features testing. A multi-temporal approach was shown to detect biomass patterns present in slides.

Challenges that need to be addressed include the affect of varying local incidence angles, which is magnified by the relatively steep slopes of levees. In addition, vegetation differences affect the dielectric values that determine radar backscatter so it is difficult to separate the effects of surface roughness from vegetation differences. Since the multi-temporal approach gives data on biomass differences, it may be useful in combination with other features. In ongoing work, we are exploring the benefits of adding ancillary features with other features for the classification task, as well as combining information (features) extracted using various approaches into a single unified classification paradigm for levee health classification.

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