Slope Stability Monitoring through Impedance Imaging

Alistair Boyle[1], Paul Wilkinson[2], Jonathan Chambers[2], Nolwenn Lesparre[3], Andy Adler[1]
[1]Carleton University, Ottawa, Canada, {boyle, adler}@sce.carleton.ca
[2]British Geological Survey, [3]Institut de Radioprotection et de Sûreté Nucléaire

Abstract: A technique for monitoring slope stability in a geological setting through impedance tomography is demonstrated. An iterative absolute Gauss-Newton solver simultaneously constructs estimates of the underground resistivity distribution and movement of the stimulation and measurement electrodes. The results are a step toward demonstrating that a cost effective and potentially predictive monitoring technology could be practical.

1 Introduction

Slope stability is a key issue for land uses where slope morphology and annual changes in soil and rock water saturation lead to movement. Monitoring of these slip prone regions in the railway, mining, oil and gas, and construction industries is currently available through laser range finding and similar surface observation technologies which can not provide remote, unmanned and cost effective monitoring over time. Slope Stability is important for long term railway embankment safety and for determining mine tailings pile slope angles. To corporations involved in these industries, slope stability translates into a significant risk/cost balance. The challenging task of managing landslide risk may be mitigated to some degree through insight gained from monitoring and understanding the geophysical process.

In sedimentary rock, resistivity is related to water saturation through Archie's Law [1]. A common adaptation of Archie's Law, the Waxman-Smits equation [2], accounts for the effects of clay, common in top soil and non-sedimentary rock, by adding variables that support variation in ion mobility and ion concentration. The geology of a region is relatively fixed on a human time scale, such that completing a lab correlation provides accurate estimates of water saturation and hence, can provide a prediction of slope stability through static slope stability analysis techniques. An accurate and ongoing estimate of electrode movement provides immediate warning of slope movement at a reduced cost compared to the previously mentioned technologies.

2 Reconstruction

Measurements have been taken since 2008 on a slow moving land slide located in the British countryside [3]. An absolute Gauss-Newton iterative solver that simultaneously solves for the combined log conductivity and electrode movement using this data was developed in the EIDORS environment (Figure 1).

An initial background estimate was constructed by finding the best-fit average resistivity of the apparent resistivity measurements. Initial electrode positions were determined via GPS measurements.

The conductivity Jacobian was calculated using the adjoint method for conductivity and scaled for log conductivity using the chain rule.

$$\mathbf{J}_{\ln\sigma} = \frac{\partial \mathbf{b}}{\partial \ln\sigma} = \frac{\partial \mathbf{b}}{\partial \sigma}\frac{\partial \sigma}{\partial \ln\sigma} = \frac{\partial \mathbf{b}}{\partial \sigma}\sigma = \mathbf{J}_\sigma \sigma \qquad (1)$$

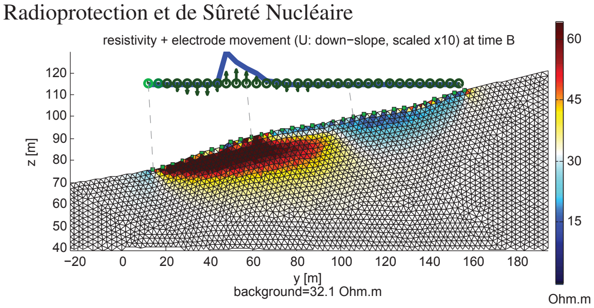

Figure 1: Simultaneous reconstruction of resistivity and electrode movement after 4 Gauss-Newton iterations; green arrows are reconstructed down-slope movement, blue line is measured movement (GPS)

The movement Jacobian [4] was estimated by constructing a down-slope and cross-slope movement perturbation using alternate electrode sites. Alternate electrode sites were preferred over rank-1 updates [5] because rank-1 updates restrict the magnitude of the electrode movements to within a single surface mesh element in the forward model where high mesh density is critical to accurate measurement estimates. Performing movement Jacobian perturbations in this fashion increased the original dipole-dipole stimulation and measurement pairs P_{orig} such that

$$P_M = N_{e\ell} D_{DoF} P_{orig} \qquad (2)$$

where the total stimulation/measurement pairs for movement estimates P_M increased by the number of electrodes $N_{e\ell}$ and movement degrees of freedom M_{DoF}. Many of the calculated measurements required for this approach are redundant across each electrode movement. A generic stimulation and measurement pattern improvement routine was developed to minimize computation time for the forward solutions by rearranging the forward solution results and removing duplicate measurements. This routine improved run times by two-orders of magnitude ($N_{e\ell} = 32$, $D_{DoF} = 2$, $P_M \simeq 37000$) from 45 minutes to 3.75 minutes for the rearrangement and approximately 15 seconds for each new forward solution (Intel Xeon 2.6GHz, 8 cores, 64GB mem.) of which there was one per Gauss-Newton iteration.

3 Discussion

Simultaneous reconstruction of absolute impedance and electrode movement is a practical and promising method for monitoring slope stability. While prior work has reconstructed electrode movement and absolute impedance separately [6], to our knowledge, this is the first time they have been reconstructed simultaneously.

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Systems and Computer Engineering
Carleton University, 1125 Colonel By Drive
Ottawa, Ontario, K1S 5B6, Canada
adler@sce.carleton.ca
+1 (613) 520-2600

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