Memo of Transmittal

Date: Friday June 14, 2019
To: Professor Robb Moss
CC: Professor Erin Martin-Elston
From: Micah Jeffries and Marcos Martinez
Subject: Recommendation report on how to best predict landslides

Attached is the recommendation report regarding the different methods for predicting landslides. The purpose of this report is to inform Robb Moss, a civil engineering professor at Cal Poly, of the best available method by preforming a cost and benefit analysis for each proposed method.

Recommendations

Throughout our report, we analyzed three possible methods for predicting landslides. Each option was evaluated based on accuracy, reliability, availability, cost-efficiency, and how effectively each can provide an early warning of a landslide. The three options are as follows:

- Use AM Radio broadcasting to determine water content within the soil
- Use SVM to map which areas are highly susceptible to landslides
- Use MEMS **accelerometers** and sensors to alert scientists of an imminent landslide

Resources

In order to make a well-informed recommendation, we used the following sources:

- Lecture with you
- "Cal Poly's Fremont Hall will remain closed for another year" (online article) [1]
- "Deadly California mudslides show the need for maps and zoning that better reflect landslide risk" (online article) [2]
- "Rainfall and Landslides in Southern California" (online article) [3]
- "Landslide Causes and Triggers" (online article) [4]
- "Sensing Performance Evaluation of Landslides Prediction System Using Public AM Radio Broadcasting" (conference proceeding) [5]
- "Landslide Susceptibility Mapping in Chittagong District of Bangladesh using Support Vector Machine integrated with GIS" (conference proceeding) [6]
- "A Low-Cost IoT Framework for Landslide Prediction and Risk Communication" (scholarly article) [7]

Findings

We organized the information on our project into different sub-sections where each sub-section talks about each proposed method. This information can be found in the *Results* section of the report. We have then preformed an analysis for you based on these results, which can be found in the *Conclusions* section.

Final Recommendation

Our final recommendation is to use SVM to map which areas are highly susceptible to landslides. This method is the most well-balanced among the criteria you are searching for.

Note: All technical words in **bold** are defined in the *Glossary* section.

Recommendation Report

How to Predict Landslides

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Prepared for: Professor Robb Moss

Date Submitted: June 14, 2019

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Introduction

Cal Poly's Fremont Hall, which houses 215 students, has remained closed for the 2018-19 academic school year due to the landslide that occurred in February of 2017. The landslide threatened the buildings structure and forced an emergency student evacuation [1]. Fortunately, no one was killed during this natural disaster, but it easily could have gone the other way. The U.S Geological Survey estimates that landslides kill between 25 to 50 people a year in the U.S. On average, landslides have a higher death toll than earthquakes and volcanoes [2].

It has been two years since the first Fremont slide but a 2nd slide recently happened in March of 2019. Engineers and geologists failed to conduct enough research when first constructing Fremont Hall. First off, the workers cut the tip of the mountain next to Fremont which made the hillside less stable. Secondly, the hillside is composed of **Franciscan Mélange** which is well known among geologists to have weak stability. Fremont is the only structure within the radius that is most susceptible to landslides. Currently they are still working to fix the problem and are conducting a lot of field tests such as cone penetration to learn more about it. Engineers and geologists are still unsure whether Fremont should be demolished or reopened to students but from what it looks like, it won't be reopened anytime soon due to liability concerns.

It is imperative that we bring attention to this matter because states along the west coast, including California, are especially vulnerable to landslides. Many parts of coastal California are subject to coastal landslides due to cliff **erosion**. Cliff erosion can occur when substantial rainfall causes cliffs to collapse from the top, or when waves reach far enough inland and erode the bottom of a cliff resulting in a burial [3]. Given that this hazard has affected Fremont Hall, this is a serious topic that should be taken into consideration, especially since SLO County is populated with hillsides.

Background: A landslide is the movement of rock or soil moving down a slope that is influenced by gravity. This slope movement can be categorized into five different types which are: falls, slides, spreads, flows, and topples. The stability of a slope is determined by many factors that could ultimately lead to a landslide. The type, strength, and structure of the material along with the geometry is what ultimately leads to failure [4]. The city of San Luis Obispo, along with many other cities, fall along the coastal region of California, which is highly susceptible to landslides. Landslides are more common in the winter, but it could happen anytime when the soil of the hillside doesn't have any moisture.

Methods

A variety of methods were implemented in our research process. Our primary research method was the lecture and tour that you gave on the Fremont Hall landslide. Our secondary research method was broken up into two categories: scholarly online resources and other online resources.

Lecture with You: In order to gain a thorough understanding of landslides and determine the necessary criteria when evaluating different solutions, we attended your lecture and field tour of the Fremont Hall landslide incident. The Fremont Hall incident is perfectly representative of potential landslides that can occur in SLO County, which is great since we wanted to focus our project in this area.

Scholarly Online Resources: The scholarly resources that we used included scholarly articles and conference proceedings. These scholarly resources were accessed through the Cal Poly Kennedy library database. The main purpose of these sources was to find three viable methods for landslide prediction. Our scholarly sources were as follows:

- "Sensing Performance Evaluation of Landslides Prediction System Using Public AM Radio Broadcasting" (conference proceeding) [5]:
  This conference proceeding examines our first proposed method for landslide prediction. The idea behind this method is to broadcast AM radio waves into the soil and from there determine how much water content lies within the soil.

- "Landslide Susceptibility Mapping in Chittagong District of Bangladesh using Support Vector Machine integrated with GIS" (conference proceeding) [6]:
  This conference proceeding examines the recently developed technology of Support Vector Machine or SVM. This technology improves scientists' abilities to determine which areas are susceptible to landslides.

- "A Low-Cost IoT Framework for Landslide Prediction and Risk Communication" (scholarly article) [7]:
  This scholarly article examines our final proposed method: Microelectromechanical systems or MEMS. This method utilizes **accelerometers** and sensors to monitor landslides and warn people of an imminent landslide.

Other Online Resources: The other online resources included online articles, local mustang news articles, and some landslide statistics. The main purpose of these sources was to educate ourselves further, beyond the information provided in your lecture, on the dangers of landslides and what triggers them. Our other online sources were as follows:

- "Cal Poly's Fremont Hall will remain closed for another year" (online article) [1]:
  This mustang news article provided us with details on the Fremont landslide incident. It gave us background information about the slide and a sense of direction from where to go after this article.

- "Deadly California mudslides show the need for maps and zoning that better reflect landslide risk" (online article) [2]:
  This article provided some statistics on the deathly consequences of landslides and shows that engineers and geologists are not paying enough attention to hazardous landslides. Landslides impact localized areas so it does not get widespread attention. Engineers and geologists need to inform the population on landslides and how to prepare for them.

- "Rainfall and Landslides in Southern California" (online article) [3]:
  This article examines the causes of landslides along the California coast. California is highly susceptible to landslides and they are mostly triggered by intense and/or prolonged

rainfall. This article also describes the different types of landslides that could occur such as shallow landslides and deep-seated landslides.

- "Landslide Causes and Triggers" (online article) [4]:
  This article provides some general background information on what triggers landslides. It includes information on how to successfully assess failure susceptibility such as material strength, structure, and topography preconditions of hillside slopes.

Results

This section provides extensive information on our three proposed methods for landslide prediction. The information provided below mainly comes from our scholarly sources.

AM Radio: As a result of global warming, concentrations of heavy rain have been increasing, which is causing an increase in landslide incidents [5]. According to your lecture, the Fremont Hall landslide was a result of the rainy season. High concentrations of rain in SLO County during January and February of 2017 caused the stability of the hillslide slope to collapse due to high concentrations of water within the soil. The idea behind broadcasting AM radio waves into the hillside is to measure the amount of water content within the soil. Figure 1 below shows a schematic of bistatic radar technology. The reciever, labbelled "RX" in figure 1, recieves a direct wave from the radio station and a reflected wave from the mountain [5].

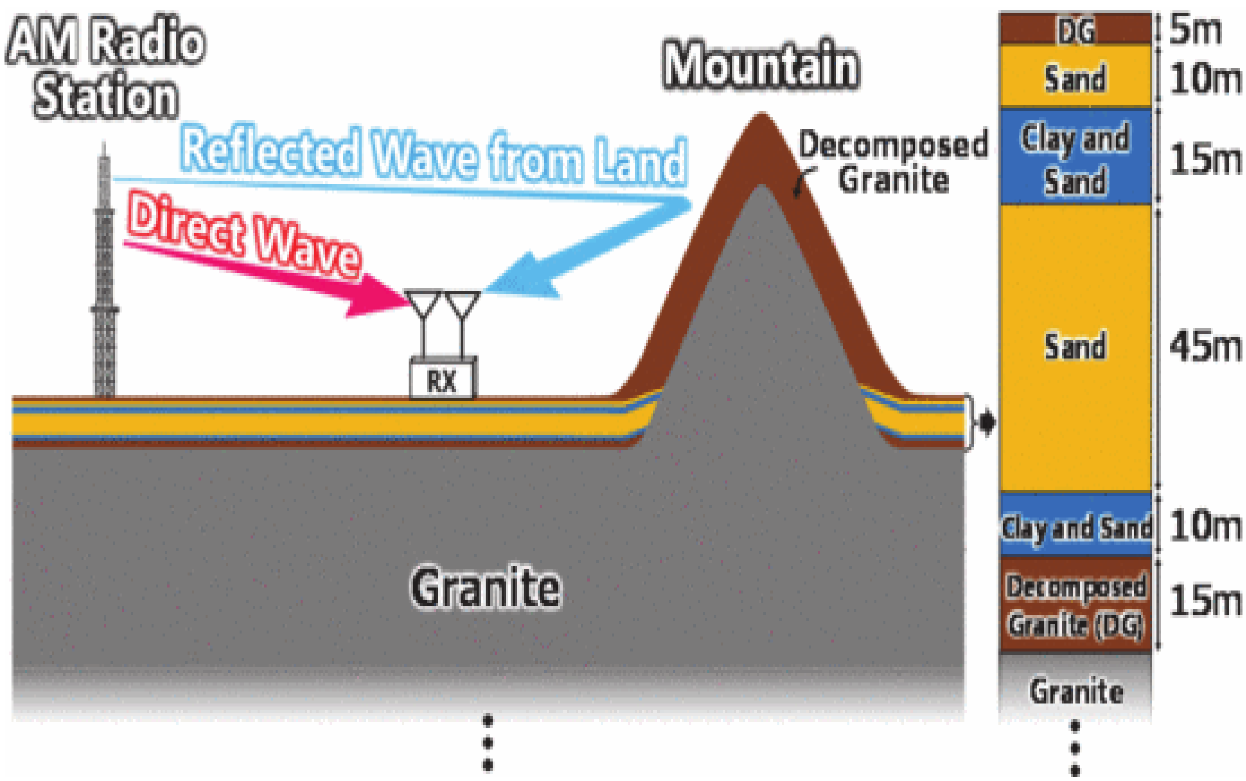

Figure 1: Schematic view of bistatic radar technology [5].

Using the relative **intensities** of the direct wave and the reflected wave, geologists can determine the amount of water content within the soil. Geologists use the intensity of the direct wave as a reference point since it never changes. The intensity of the direct wave is divided by the intensity of the reflected wave to give a ratio given in **decibels** or dB that measures relative intensities. Thus, the only two variables that are changing are the ratio of relative intensities and the water content within the soil. As the amount of water content increases, the ratio of relative intensities decreases. It is well known among geologists that a percentage level of 5% water will generally trigger a landslide. When the ratio of relative intensities is 7 dB or less, the percentage of water content within the soil is 5% or higher. Thus, geologists can take emergency action when the ratio of relative intensities from the receiver reaches 7 dB or less [5].

SVM: According to you, in order to perfrom a sucessful analysis of the Fremont Hall landslide, we need to take three factors into consideration: geometry, geology, and strength. One of the problems with the hillside next to Fremont Hall is the sudden change in slope. The hill starts off at a relatively flat angle at 13.5 degrees with the ground, then it jumps to a slope of 22.5 degrees with the ground. This creates a **slip plane** below the ground where a landslide is more likely to occur. Another problem with the hillside next to Fremont Hall is the fact that the hillside is composed of **Franciscan Mélange**. This type of soil does not have great stability and when combined with the poor geometry, the hillside is very susceptible to landslides. The idea behind using SVM is to take all of these landslide triggering factors as **parameters** of a math function (**kernel**) and to establish a linear or non-linear relationship between them. When a relationship can be established, geologists can quantify how susceptible a certain area is to landslides [6].

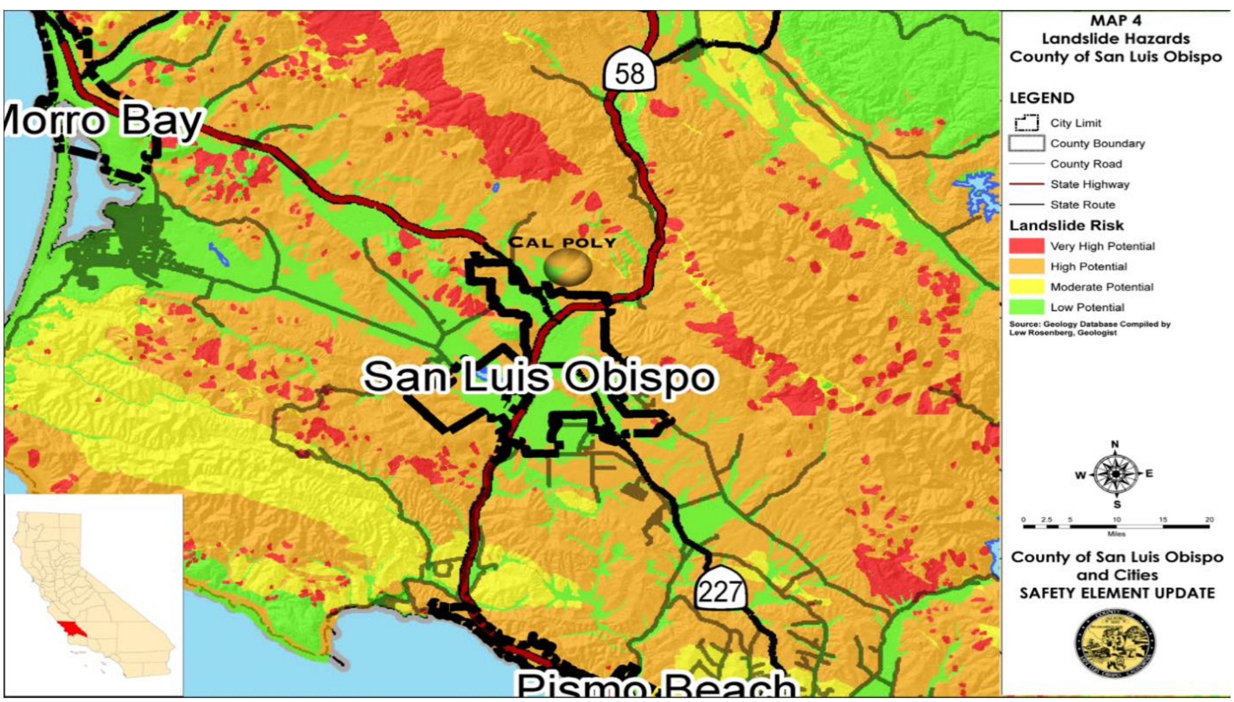

Figure 2: Map of SLO County highlighting areas with high potential for landslides [8].

In figure 2 shown above, ten major landslide conditioning parameters such as **topography**, slope-angle, slope-curvature, slope-aspect, distance to-stream, road and fault line, precipitation, Normalize Difference Vegetation Index (NDVI) and soil type data are used as the triggering factors for the landslide susceptibility mapping in the corresponding area. Six different types of kernel functions namely linear, cubic, quadratic, fine-Gaussian, coarse-Gaussian and medium-Gaussian are generally used to establish a linear or non-linear relationship between the landslide triggering factors. Each kernel function is tested for accuracy in the corresponding area. Generally, each kernel function has an average accuracy percentage of over 97%, which is a very high accuracy rate. The kernel function with the highest accuracy rating in the corresponding area is then used to map landslide susceptibility as shown in figure 2 [6].

MEMS: When all other means fail to predict where a landslide will occur, quick action is needed to avoid injury or even death. Thankfully in the case of the Fremont Hall landslide, no one was injured or killed in the incident. There already exists an **IoT framework** in the hillside next to the Fremont Hall that was able to warn the people in the building of an emergency evacuation. However, these existing landslide monitoring technologies are very expensive and are unable to look beneath the terrain's surface. Implementing MEMS-based sensors in the existing IoT frameworks provides a low-cost solution that can be installed beneath the terrain's surface. The framework, as shown in figure 3 below, consists of a sensing unit, a data-logging and thresholding unit, and an alert generator [7].

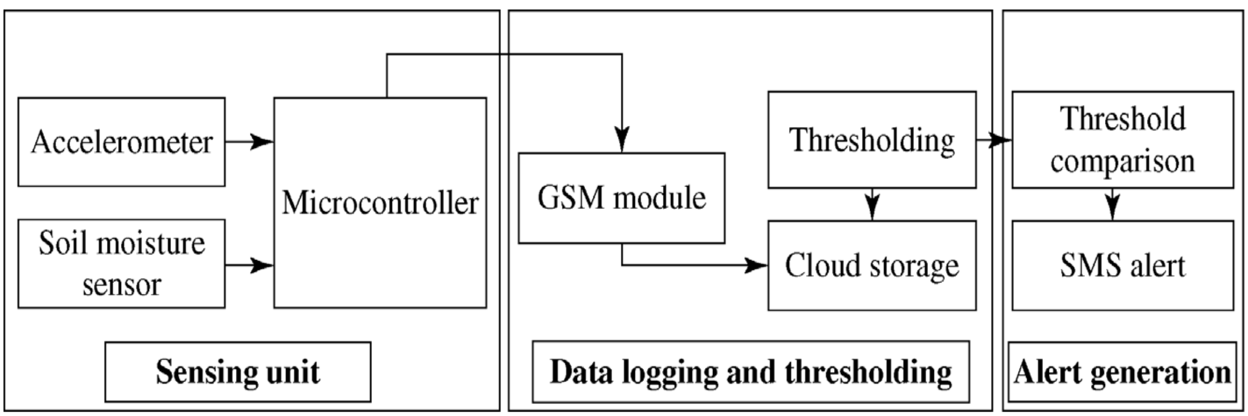

Figure 3: Design of the microelectromechanical system for landslide monitoring [7].

MEMS is a technology that uses advances in fabrication techniques to embed an electromechanical system on a single chip. The soil moisture sensor senses soil moisture and soil movement (acceleration) and the **accelerometer** measures the resulting acceleration. From there, the information is passed on to the **microcontroller** where it is given an **analog** value. The GSM module then takes these values and passes them to a database on the cloud. The values for soil moisture and soil movement are then compared to a predefined threshold. When the sensor values breach the predefined threshold values, a landslide is in progress. From there, the alert-generating unit is triggered, and SMS alerts are sent via mobile phone. The alert-generating unit has the provision of preregistering mobile phone numbers for sending SMS alerts [7].

Conclusions

Given all the information that we have gathered on each proposed method, we now provide you with a cost and benefit analysis for each option. Based on your lecture, we have decided to compare each option while considering five criteria: accuracy, reliability, availability, cost-efficiency, and how effectively each can provide an early warning of a landslide. These criteria will allow us to determine which option is the most optimal for SLO County. See table 1 below for reference on how we scored each option.

Table 1: Decision Matrix that quantifies how each option compares against one another.

Weight	15%	30%	25%	10%	20%	100%
Option	**Cost**	**Accuracy**	**Reliability**	**Availability**	**Early Warning**	**Score**
AM Radio	5	8	9	8	8	7.80
SVM	8	9	8	8	6	7.90
MEMS	10	8	5	9	9	7.85

Option 1: Use AM Radio broadcasting to determine water content within the soil.

Implementing an AM radio station is the most expensive option. On top of high installation costs, there are regular maintenance costs that come with it. However, this option has a high accuracy in determining the amount of water content within the soil. Determining the amount of water content is very important as it indicates if a hillside is susceptible to a landslide. Geologists have conducted many field tests and they indicate that this technology is very reliable in predicting landslides. Although not as important, this technology also has been around for a long time and is readily available. Finally, this technology has a great system for providing an emergency evacuation in the case of an unpredictable landslide. Should the ratio of relative intensities drop below a certain threshold (refer back to *Results* section), geologists can tell right away if there is an immediate threat. Overall, this technology has many great factors, but the cost of implementation is a serious concern [5].

Option 2: Use SVM to map which areas are highly susceptible to landslides.

Implementing the SVM method provides the second least expensive option. Most of the cost would come from collecting data for the corresponding area. This option also provides the most accurate solution. As mentioned in the *Results* section, the kernel functions have an average accuracy of over 97%. Field tests have also indicated that this technology has an error rate of just over 5% when considering where landslides are most likely to occur, which means this technology is very reliable. This technology, while still relatively new is readily available as well. Despite all these pros, this technology is unable to provide an efficient early warning of an imminent landslide. This does not present much of a problem as this technology minimizes unpredictable landslide incidents with its high accuracy, but it still remains a concern [6].

Option 3: Use MEMS accelerometers and sensors to alert scientists of an imminent landslide.

Implementing MEMS-based sensors into the existing IoT Framework provides the least expensive solution. When tested in the laboratory, the entire IoT framework only costs 32 USD. The cost would equal more for the actual size implementation, but it would still cost significantly less than the other two options. Laboratory tests indicate that this technology also has a high accuracy rating when determining the soil moisture and the acceleration of the soil. While MEMS does have high accuracy and is cost-efficient, it has only been tested in the laboratory and is very unreliable. Designers of the product are optimistic but are not certain that this technology will work when implemented in the real world. However, this technology consists of many parts such as accelerometers and sensors that are inexpensive and readily available. This technology also has the most efficient method for warning people of an imminent landslide. Unlike the first option, where the system warned geologists only, the alert generator unit sends alert SMS messages to everyone in proximity of the landslide within seconds. While this technology sounds promising, it has not had enough testing in the real world [7].

Recommendation

All three options discussed in our report provide great and innovative ways for predicting landslides. However, after considering the criteria that you are looking for, we recommend using SVM to map which areas are highly susceptible to landslides. While this option is unable to provide an early warning of an imminent landslide, its high accuracy and reliability make this option the best solution for landslide prediction in SLO County.

Glossary

Franciscan Mélange: a type of soil; well known among geologists to have weak stability

Erosion: to cause to deteriorate or disappear [9]

Intensity: the magnitude of energy per unit area [10]

Decibel: a unit for expressing relative intensity [11]

Slip Plane: a chunk of soil beneath the ground that moves freely while the surrounding soil is locked in place

Parameter: an independent variable used to express the coordinates of a variable point and a function [12]

Kernel: a subset of the elements of one set that a function maps onto an identity element of another set [13]

Topography: the art or practice of graphic delineation in detail usually on maps or charts of natural and man-made features of a place or region especially in a way to show their relative positions and elevations [14]

IoT Framework: foundation for connecting sensors, actuators, and other small technologies to improve automation and control in various operations [7]

Accelerometer: an instrument for measuring acceleration or for detecting vibrations [15]

Microcontroller: an integrated circuit that contains a microprocessor along with memory and associated circuits and that controls the functions of an electronic device [16]

Analog: a mechanism in which information is represented by continuously variable physical quantities [17]

Note: All terms not cited were defined by you in your lecture

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