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Exploration of Drone and Remote Sensing Technologies in Highway Embankment Monitoring and Management (Phase I)

Figure 1. FLIR Vue Pro R thermal camera mounted on DJI Inspire 2

Figure 2. MicaSense RedEdge multispectral camera mounted on DJI Inspire 2

INTRODUCTION

Louisiana highway embankments were sometimes built with high plasticity soils due to historic reasons. Over time, some embankments have experienced surface sliding failures, resulting in a safety issue and causing traffic disruptions. Since no warning system is available for this type of failure, the Louisiana Department of Transportation and Development (DOTD) can only respond to them after the fact with costly remediation. The reason for lacking a proactive highway embankment maintenance, management, and warning system is that the embankment system is extensive and assessing their condition using traditional site inspections by trained engineers and technicians is laborious, time consuming, and costly.

It is worthwhile to point out that this kind of soil weakening process in an earth embankment is, based on field observation, very difficult (if not impossible) to predict. One such example is the slope failure at the intersection of interstate I-10 and Bluebonnet in Baton Rouge, Louisiana. The first slope slid in 2000 after serving approximately 20 years, but the second one occurred in about 2020, approximately 20 years apart. Since these two slopes were built at the same location and with the same material at the same time, it can be assumed that this kind of surface sliding is a random event. Therefore, the field observation of embankment soil surface moisture condition becomes very important for the evaluation of their stability. Since the soils in a slope, before sliding, need to store enough moisture with a sustainable period of time, both of them together can be a good indicator of slope surface stability.

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OBJECTIVE

The objective of this research study was to evaluate the capability of drone-mounted remote sensors to estimate soil moisture and its spatiotemporal variability in an embankment/dam, thus assessing the feasibility of using remote sensing technologies to evaluate the risk of slope failure of the embankment/dam.

SCOPE

Two drone cameras were evaluated in this study: FLIR Vue Pro R, a radiometric thermal camera (Figure 1), and MicaSense RedEdge, a multispectral camera for precision agriculture (Figure 2). Specifically, they were evaluated both in laboratory and field settings for their accuracy, repeatability, and reliability.

Laboratory testing was carried on an embankment soil to evaluate the sensitivity of the thermal camera on soil moisture under various conditions. The effect of camera mounting height and camera heating effect on thermal readings was also evaluated in the laboratory. The field testing was then first conducted at the Pavement Research Facility (PRF) of Louisiana Transportation Research Center (LTRC) to further test the capabilities and limitations of both thermal and multispectral cameras. The testing was focused on a soil embankment about 150 ft. long and 20 ft. high. The soil embankment slope was divided into different moisture zones by wetting them with different gallons of water. The image data of the slope was captured by both the thermal and multispectral camera. A stand-alone geotagging module was also tested to automatically geotag the thermal images during the field testing at PRF.

Finally, the field data were collected at the I-10 at LA30 embankment site using both thermal camera and multispectral camera and at Iatt Lake Dam and Vernon Lake Dam with thermal camera only.

METHODOLOGY

This research explored the capabilities of drone-mounted remote sensing sensors for soil moisture detection on embankment soils for their accuracy, repeatability, and reliability. The two drone cameras evaluated in this study (the FLIR Vue Pro R and MicaSense RedEdge) were evaluated both in a laboratory setting on an embankment soil and a field setting at various embankment/dam sites.

CONCLUSIONS

- The study showed promising results in using drone-mounted thermal camera to qualitatively distinguish different moisture zones, which is good enough to identify potential problematic areas and locations as highway embankment and dam inspections. More study will be needed if we want use infrared thermography technology to quantitatively determine the soil moisture content. The drone-based infrared thermography technology cannot replace the expertise of an experienced inspector in its current state, but it can be used as an effective tool for rapid mapping highway embankment and dam slope surface moisture conditions with full coverage of inspected sites.
- A multispectral camera alone was not effective to distinguish different moisture zones with the soil moisture estimation methods explored in this study.
- The index combining land surface temperature and vegetation within the NDVI/LST space showed promising results in this study. However, due to limited resources available to the researchers in this study, this approach was not fully explored.
- This research mainly focused on the spatial variation of moisture-dependent land surface temperature in a manner aimed at assessing the condition of a highway embankment and dam. The study did not explore the variation of soil moisture content over time in an embankment or dam, which actually has more practical implications and should be investigated in future studies.
- Image processing and analytical tools are needed for constructing the maps and processing the data (i.e., image data extraction, categorization, and interpretation) with the characteristics of real-time analytics and reporting, high accuracy, and user friendly.
- Only limited electromagnetic spectral bands were investigated in this research. Soil moisture content may be more sensitive to other spectral bands that were not explored in this study, e.g., SWIR.

RECOMMENDATIONS

- DOTD engineers explore and adopt market-available drone-based infrared thermography technology in routine highway embankment and dam inspections to supplement traditional ground inspections.
- Future research can explore more electromagnetic spectral bands in the future to find the band or combination of bands that is most sensitive to the combined effects of soil and moisture. Hyperspectral imagery can be such an option.
- Various techniques of combining land surface temperature and vegetation mapping within vegetation index/temperature (VIT) space should be explored considering vegetation is very common in soil embankment and dam.
- Future research on spatiotemporal variation of moisture-dependent land surface temperature is recommended to help better monitor the risk of stability failure of the embankments/dams.
- Additional research study is also recommended to explore the use of infrared thermography to quantitatively determine the soil moisture content.
- Future researchers are recommended to work together with software developers to develop an image processing and analytical tool to serve the purpose of highway embankment and dam inspection.