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Development and experimental calibrations of a multifunction slope monitoring device - Smart Pole

Développement et étalonnages expérimentaux d'un dispositif de surveillance multifonctionnel de pente - Mât Intelligent

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ABSTRACT: Slope failures pose a significant threat to infrastructure and human safety, primarily influenced by factors such as rainfall, surface runoff, changing soil water content, and slope movement. However, most of the existing technologies rely on separate devices with limited integration capabilities. This study addresses these limitations by developing the Smart Pole, a multifunctional slope monitoring device. Equipped with sensors including a rain gauge, humidity and temperature sensor, surface water runoff sensor, camera, soil moisture content sensor, and an Inertial Measurement Unit (IMU), the Smart Pole offers versatility in assembling and disassembling sensors to meet specific monitoring needs. The device incorporates a power supply system and a Microcontroller Unit (MCU) for data collection, processing, and transmission using LoRa technology. This article introduces the purpose, functional requirements, and components of the Smart Pole. Additionally, laboratory calibration and field testing were conducted to validate the Smart Pole's performance. The testing process presents the calibration process of the device's soil water content measurements. The final performance presents the integration of the Smart Pole.

RÉSUMÉ: Les glissements de terrain représentent une menace significative pour l'infrastructure et la sécurité humaine, influencés principalement par des facteurs tels que les précipitations, le ruissellement de surface, la variation de la teneur en eau du sol, et les mouvements de pente. Cependant, la plupart des technologies existantes reposent sur des dispositifs séparés avec des capacités d'intégration limitées. Cette étude aborde ces limitations en développant le Mât Intelligent, un dispositif de surveillance de pente multifonctionnel. Équipé de capteurs tels qu'un pluviomètre, un capteur d'humidité et de température, un capteur de ruissellement d'eau de surface, une caméra, un capteur de teneur en humidité du sol, et une Unité de Mesure Inertielle (IMU), le Mât Intelligent offre une polyvalence dans l'assemblage et le désassemblage des capteurs pour répondre aux besoins spécifiques de surveillance. Le dispositif intègre un système d'alimentation et une Unité de Microcontrôleur (MCU) pour la collecte, le traitement et la transmission des données via la technologie LoRa. Cet article présente l'objectif, les exigences fonctionnelles et les composants du Mât Intelligent. De plus, une calibration en laboratoire et des tests sur le terrain ont été réalisés pour valider les performances du Mât Intelligent. Le processus de test illustre la calibration de l'appareil pour les mesures de la teneur en eau du sol. La performance finale met en avant l'intégration du Mât Intelligent.

Keywords: Slope stability; monitoring device; laboratory calibration.

1 INTRODUCTION

In landscapes susceptible to the repercussions of vigorous meteorological events, understanding and analysing rainfall-induced slope failures become crucial. The failure of slopes due to excessive rainfall has a sequence of occurring in stages, initiating with the saturation of the slope surface and followed by infiltration into the interior of the slope. This process can induce several potential slope failure conditions, such as deformations, cracks, sliding, and in dire situations, complete slope collapse. It's noteworthy that the acceleration in the severity of deformation is often directly related to increasing rainfall amount, thus necessitating a deeper examining monitoring and mitigation strategies in the context of these phenomena. To effectively manage and potentially curtail the progression of failure phenomena, a diligent monitoring framework is indispensable.

To accomplish the objective of gathering field data for subsequent data analysis, Karunarathne et al. (2020) illustrated the use of an Internet of Things (IoT) device equipped with wireless communication capabilities for monitoring landslides. This research highlighted the evolution of IoT technology for data collection, curation, and presentation, with the potential for future machine learning applications. Accompany with the landslide susceptibility assessment, Jeong et al. (2020) utilized wireless sensor network technology to connect multiple individual sensors to monitor a potential slope failure threatened by rainfall events. With the assistance of diverse monitoring sensors, Bai et al. (2020) constructed a microservices architecture incorporating a web service to enhance the provision of early warning services for landslide hazards. Li et al. (2021) developed a risk assessment methodology that leveraged 5G and IoT technology to measure potential landslide indicators, including surface displacement, rainfall, and ground cracks. This early warning system was implemented and validated using an actual project as an example. To explore the failure mechanism of shallow landslides, research by Bovolenta et al. (2020) has revealed that the water content of the slope surface serves as a important indicator for reliably illustrating the slope failure process. Chen et al. (2020) presented the calibration and filed performance of the tilting measurements on a underground structure in a landslide area.

Monitoring is important for tracking slope failures, collecting data for future models, and enhancing safety and sustainability. This study presents the Smart Pole device, equipped with sensors for soil water content, runoff, humidity, temperature, tilt, camera, and rain gauge, plus a MCU, storage, and power. This article presents calibrating the soil water content sensor and the camera's trigger mechanism, activating at excessive tilt.

2 DESIGN AND METHODOLOGY

An effective monitoring system comprehensively incorporates multiple factors that contribute to potential failure, with rainfall amount being at the forefront. However, merely observing rainfall quantities is not sufficient. Analysing the soil water content of the slope surface offers insight into the amount of infiltration, which is a key element influencing slope stability. Once surface runoff is initiated, the velocity of water runoff and the volume of water accumulating on the slope during flow can affect the stability and erosion of the slope.

When slopes begin revealing signs of failure, observing and recording of the slope inclination can provide important indications regarding possible initiation and progression of failure. Employing on-site cameras, which can be triggered when certain failure criteria are met, can offer visual documentation of the failure process. Additionally, considering environmental factors like humidity and temperature is also crucial, as these can influence the micro-environmental conditions of the slope.

As illustrated in Figure 1, the distinct levels of the Smart Pole were each equipped with sensors meticulously tailored to gauge different parameters and facets of slope stability. Among the various sensors, there are two functional blocks. Each block has its own memory storage and MCU. A key distinction lies in the triggering logic for the camera. As illustrated in Figure 1, when IMU records a tilting angle surpassing a specific threshold—such as exceeding 15°—the camera is triggered to capture a picture.

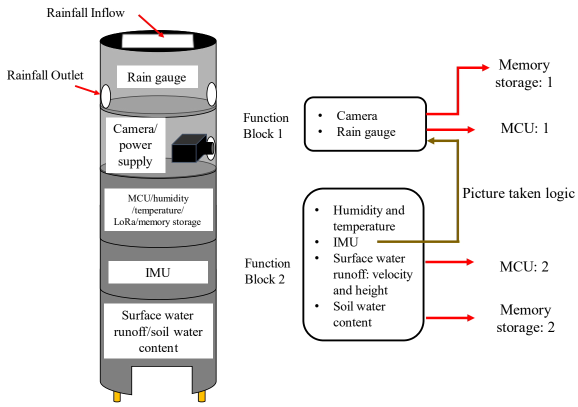

Figure 1. Scheme of Smart Pole device.

3 CALIBRATION AND PROTOTYPE ASSEMBLY DEMONSTRATION

3.1 Calibration of soil moisture measurement

The function of measuring soil moisture was utilized by the YL-69 hydrometer sensor. Three distinct soil types were meticulously prepared for calibration purposes: reddish laterite clay (typical to the local soil), Ottawa sand, and a 1:1 weight mixture of reddish laterite and Ottawa sand. Utilizing the Harvard Miniature Compaction approach, soil samples were produced with a height of 71mm and a diameter of 33mm. Soil samples were compacted using a combination of diverse of dry soils and water. Water content within the soil samples was determined by calculating the weight of the water added to the dry soils. As indicated in Figure 2, The YL-69 sensor was inserted into each soil sample, and analogue readings were recorded. Note that, to prevent loss of water content during measurement, the sample with the YL-69 was sealed inside a plastic bag, which is not shown in Figure 2.

Figure 2. Calibration process of soil water content sensor.

In the scope of this study, both the volumetric water content (VWC) and gravimetric water content (GWC) were calibrated with sensor, providing a holistic view of the moisture within the soil samples. The calibration results are depicted in Figures 3 and Figure 4, which also display the calibration equations for the reddish laterite. These equations will subsequently be utilized in the following demonstration step.

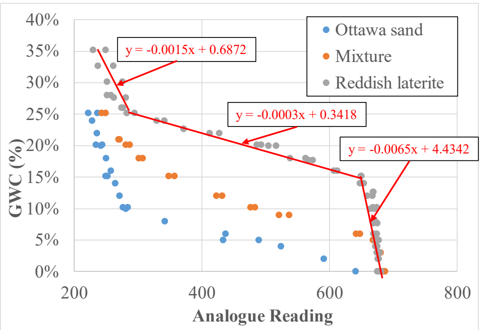

Figure 3. Calibration results of gravimetric water content (GWC) versus YL-69 analogue readings for 3 types of soils.

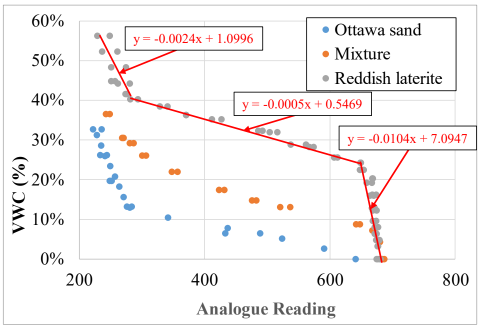

Figure 4. Calibration results of volumetric water content (VWC) versus YL-69 analogue readings for 3 types of soils.

3.2 Prototype assembly demonstration

Figure 5 displays the prototype of the Smart Pole device, with the left side illustrating the inner levels with various sensors, and the right side depicting the finished exterior. Figure 6 illustrates the field setup for measuring soil water content. On the left side of Figure 6, picture shows that the YL-69 sensor was inserted on the surface of the local soil (reddish laterite), while the right side demonstrates a laptop computer used for data collection via LoRa. The initial soil condition was dry; by pouring water from a bottle, as indicated in Figure 7, the measured analogue reading indicates increasing GWC. Figure 7 demonstrates a good agreement when compared to the calibrated data presented in Figure 3.

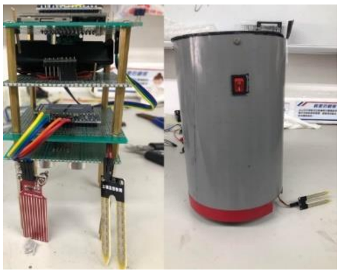

Figure 5. Smart Pole device.

Figure 6. Field testing on measuring water content.

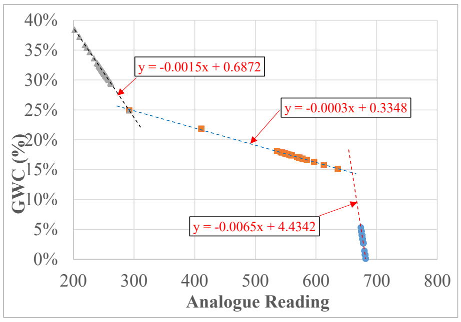

Figure 7. Field testing on gravimetric water content (GWC) versus YL-69 analogue readings.

Figure 8 displays the setup for triggering the camera action based on the tilting angles measured by the IMU (model: MPU6050). As shown in Figures 9 and 10, when the measured tilting angles exceed 15° in the X direction, a picture was taken to show the surroundings, as picture shown on the right side of Figure 8. The angle of 15 degrees was chosen arbitrarily for a functional test with taking only a single image. In future developments, the tilting angle can be set more purposefully according to specific requirements, with multiple pictures captured as needed. For further exploration, since central MCU processes all the signals within devise, additional data could serve as criteria for triggering picture capture, such as the amount of rainfall accumulation, rainfall intensity, a combination of tilting on different directions measured by the IMU, surface water runoff conditions, and soil water content.

Figure 8. Field testing on camera action triggering.

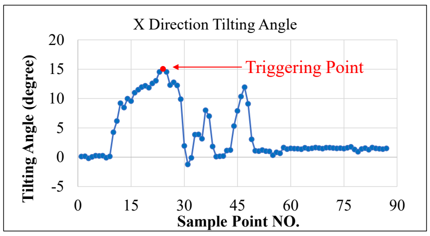

Figure 9. Field testing on camera action triggering.

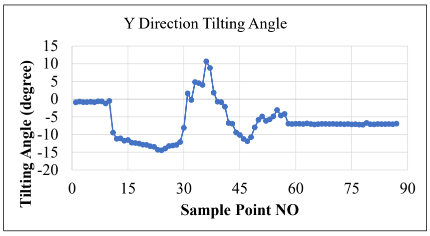

Figure 10. Field testing on camera action triggering.

4 CONCLUSIONS

This study introduces the Smart Pole device, aiming to address the challenges associated with slope failures, particularly those prone to occur during rainfall events. The primary objective of this device is to meticulously monitor and gather physical data related to the various factors affecting slope stability. The Smart Pole incorporates an array of sensors, encompassing measurements such as soil water content (e.g., GWC and VWC), surface runoff velocity and depth, slope tilting angle, humidity, temperature, camera, and a rain gauge. Each of these sensors was tailored to capture distinct micro-environmental parameters crucial for assessing slope stability.

Empowered by its self-contained power source and data transmission capability via LoRa, the Smart Pole was proficient in providing real-time data for in-depth analysis of rainfall-induced slope failures. Additionally, it served the purpose of an early warning system. To showcase the capabilities of this device, the study conducted laboratory calibrations for GWC and VWC using three different soil types: Ottawa sand, reddish laterite clay, and a 1:1 mixture of Ottawa sand and reddish laterite clay. Furthermore, a field test demonstrated the measurement of GWC in the field, with data collected and transmitted through LoRa. The Smart Pole's triggering mechanism, which activated a built-in camera based on measured tilting angles from an IMU sensor, was also showcased. This feature allowed the device to potentially record immediate environmental changes during critical slope movements.

In summary, the Smart Pole, along with its comprehensive design, calibration methods, and validated functionalities, not only enriches existing academic and practical knowledge but also lays the foundation for future research and field applications in this domain.

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