Asian Journal of Engineering Geology, 2025, Vol. 2 Special Issue, ARC-15 of IAEG, Abstract No.: 266

Extended Abstract DOI: https://doi.org/10.64862/ajeg.2025.2sp.138.266 Open Access

Point Monitoring Automatic Geohazards Warning System

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Received: August 15, 2025, Accepted: November 5, 2025

Abstract: A debris flow monitoring and warning system has been installed in the midstream section of Yusui Stream, Taiwan. The monitoring station operates fully automatically, providing early warnings without the need for manual intervention.

The system comprises two webcam cameras, two MEMS sensors, and a rain gauge. The system can detect debris flows and calculate velocity, flow height and flow rate automatically.

Once debris flows are detected, the system automatically issues warnings to the affected areas via voice messages, Line messages, broadcasts, and web-based alerts. The precision warning criteria are obtained through numerical simulation before any event.

On July 24th, 2014, Typhoon Gaemi triggered several debris flows, and the system successfully issued several warnings automatically. The entire video record, along with depth variation data, was recorded automatically.

Keywords: ***Automatic warning, Debris flow, Precision warning.***

Introduction

Most early warning systems for debris flows rely on indirect indicators, such as rainfall or hydrological indices with calibrated thresholds (Baum and Godt, 2010). These rainfall-based methods can provide early warnings on a regional scale, indicating potential for debris flows in a large area containing multiple susceptible streams. However, they cannot predict the specific time and locations of debris flow occurrences.

Direct monitoring systems using geophones, video cameras, wire sensors, ultrasonic gauges, and radar, have been developed to detect debris. These direct detection methods provide more precise warnings to affected areas. Among these devices, geophones and cameras are the most used for monitoring debris flows. Monitored information needs to be justified and confirmed by expert before real warning can be issued. This human reaction time usually takes more than an hour, so no one has used this kind of warning in real administrative system. There is currently no automatic detection and warning system using geophones or cameras, because detection thresholds vary over time and cannot yet be determined automatically.

Wei and Liu (2019) used an accumulated energy method combined with characteristic frequencies of debris flows to detect debris flow arrival. Instead of using fixed threshold, they used energy increase rate with floating threshold to avoid the problem for threshold determination. However, since this approach only considers energy variation, the events detected by geophones could include various types, such as granular flows, debris flows, or floods with high sediment concentrations. While these events may have similar energy levels, their sediment content can vary significantly. Therefore, incorporating additional information from cameras is essential for accurate detection.

The present system combines geophones and cameras with automatic identification of debris flows. After receiving data, it only takes less than 5 seconds to analyze data, confirm debris flow occurrence and send out warning through various channels.

Intelligent automatic warning system

The intelligent automatic warning system composed of two Micro-Electro-Mechanical Systems (MEMS) sensors for ground acceleration, two webcams, a rain gauge, and an industrial computer. Since a warning system is typically installed in hazardous areas, it is designed to be disposable and easy to install. Therefore, this system features low-cost hardware and efficient data analysis for real-time warning and data display. All data is digital, and transmission is achieved via internet cables.

The triaxial acceleration MEMS sensors detect ground acceleration, which is used to calculate the energy of debris flows. Webcams capture debris flow occurrences, along with average free surface elevation and surface speed. All data are transmitted through Power over Ethernet (PoE) cables to a local station, where an industrial-grade computer processes and analyzes the information. If a debris flow is detected, a warning is automatically sent to the downstream target area.

All images captured through DGM5757 webcams equipped with f 0.5mm–50mm lenses, providing high-resolution images of the region of interest (ROI) more than 600m away (Liu et al., 2022).

The warning system utilizes both MEMS signals and webcam images to detect debris flows or flood, ensuring more reliable detection by requiring confirmation from both devices. The signals from the MEMS sensors and webcams, along with the analyzed data, are displayed live on a website, as illustrated in Figure 1. All data is available in real time, with the status of all flow characteristics displayed simultaneously.

Once debris flow is detected by both the MEMS sensors and webcams, the additional velocity and depth information can be used to accurately estimate the time of impact on hazardous areas, as well as the extent of the affected region. Warning signals are sent to downstream target areas via radio waves and the internet. The system automatically broadcasts warnings in critical areas, notifies security teams, activates roadblocks, and sends messages through designated social media platforms to relevant personnel.

目前狀態 Status： 正常 Normal

平均水位 Average water level： 1.06 m

表面流速 Surface velocity： 0.75 m/s

估計流量 Estimated traffic： 3.04 cms

Figure 1, Yu-Shui monitoring station real time website.

Methodology

Ground vibration signal to detect debris flows

Debris flows or high concentration flow consist of boulders and sediment, and the rolling and sliding interactions between them result in significant collisions and friction. These contacts between boulders, sediment, and the ground surface generate strong vibrations that radiate as seismic waves through the surrounding area.

The current intelligent system uses the energy and slope methods proposed by Wei and Liu (2019). Every second, the time series from ground vibration is transformed to the frequency domain using a fast Fourier transform (FFT). The energy within the frequency range of 10 to 40 Hz is summed as the cumulative energy, P, for that second. For instance, the energy calculated from 10.1 to 11.1 seconds yields the cumulative energy at 11.1 seconds, P (11.1). The calculation uses an overlap of 0.5 seconds, with output for P every 0.5 seconds.

Before debris flows are detected, all recorded energy is considered noise. The energy noise level, Pn, is defined as the maximum energy P within a 10-minute period. The noise level is continuously updating before debris flow detection, ensuring it reflects current environmental conditions. An energy slope, S, is defined as the time derivative of cumulative energy P, and the energy slope noise level, Sn, is defined as the maximum S recorded within a 10-minute period.

The debris flow detection criteria use both cumulative energy P and energy slope S. A debris flow is detected if both $P \geq 5$ Pn and $S \geq 5$ Sn for a continuous duration of 1 second. Once debris flow is detected, the noise level stops updating until there is a continuous 30-minute period without any signal exceeding the noise threshold (Wei and Liu, 2019).

This approach does not require historic debris flow records for the calibration of thresholds. This method was tested with two well-documented but different debris flow events at the Ai-Yu-Zi Creek watershed with detection time error within 1 second (Wei and Liu, 2019). The ground vibration power is empirically correlated with the flow rate, allowing the flow rate to be estimated.

Image processing

Past research using cameras adopted particle-tracking methods to extract information from videos (Arattano and Grattoni, 2000). These methods often yield inaccurate results for natural disaster detection due to image resolution limitations and the difficulty in identifying particles.

This research, instead of using a method sensitive to variations in individual particles, we developed a method that does not require particle identification. We utilize the gray-level method to identify debris flow events (Liu et al., 2022). By calculating the gray-level in the region of interest (ROI) and monitoring changes, we can identify ongoing events. The ROI is defined to include only the surroundings of the river course, minimizing the effects of extraneous signals such as those from trees and leaves.

The video footage taken from the field is divided into individual images. For each image, a region of interest (ROI) is defined, and all analyses are conducted on the pixels within this ROI. The color of each pixel within the ROI is converted to a gray level.

When a debris flow or flood occurs, the presence of muddy and granular material darkens the image, leading to a lower AGL. Thus, the AGL can be used to represent flow conditions.

Since the front of a debris flow or flood surge is characterized by rapid changes in flow depth, velocity, and sediment concentration, the average gray level (AGL) of the image will also change rapidly. This implies that the rate of change of the AGL, or the slope of the AGL curve, should be significant.

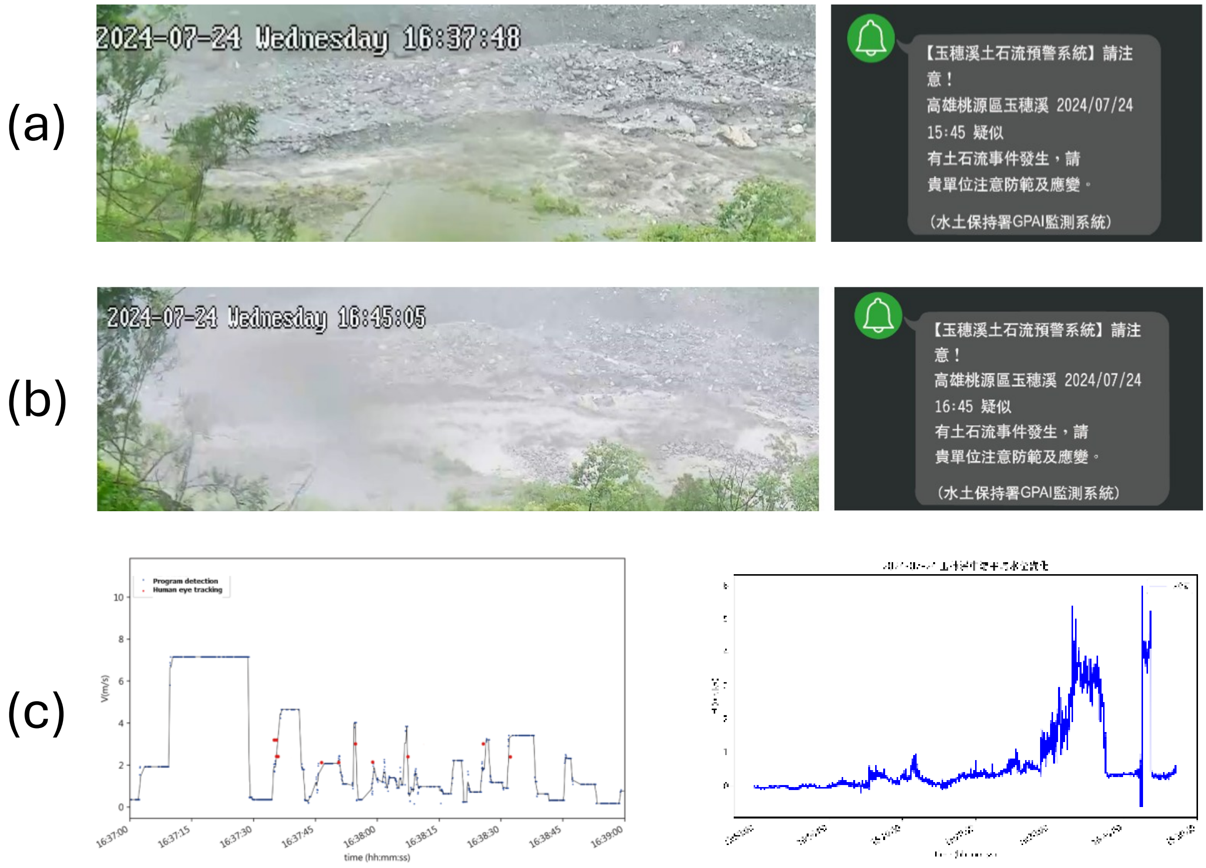
Before the arrival of debris flow, noise levels are calculated for each pixel within the region of interest (ROI) over a 10-minute period. The maximum gray-level variation for each pixel is considered its noise level, and this noise level calculation is continuously updated.

For significant change of gray level, we take an order as the minimum change. 10 times greater in gray level gives at least 2 times change in gray level slope, so slope change at least two times the maximum noise level is taken as the warning criterion. (Liu et al., 2022).

Since debris flow has a different gray level compared to water, it can be identified by analyzing the differences in gray level for each pixel in the image. Therefore, a simple search of pixel variations can identify the flow of body extent.

Successful real event record

On July 24th, 2014, Typhoon Gaemi triggered several debris flows upstream of the monitoring station. There were several waves of debris flows starting from 16:37 PM. Line messages were issued automatically for every wave. The first wave snapshot and its line messaging are shown in Figure 2 (a) and the second wave snapshot and its line warning are shown in Figure 2 (b). The real record for water levels and velocity is presented in Figure 2 (c).



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高雄桃源區玉穗溪 2024/07/24
15:45 疑似
有土石流事件發生，請
貴單位注意防範及應變。
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Figure 2, July 24th, 2014, Typhoon Gaemi: Two waves of debris flow were monitored, and warnings were issued through Line messaging software. (a) Snapshot of the first wave of debris flow at 4:37 PM along with the issued warning message. (b) Snapshot of the first wave of debris flow at 4:45 PM along with the issued warning message. (c) Monitored water level and Velocity variation.

Conclusion

The developed intelligent automatic debris flow warning system, which combines MEMS sensors, webcams, and real-time data analysis, has demonstrated effective performance in detecting debris flows and issuing timely warnings. The system's capability to detect debris flow arrival, estimate flow velocities, and provide flow depth information ensures a comprehensive understanding of flow dynamics. The integration of image processing and ground vibration analysis has enabled improved detection accuracy and the issuing of precise warnings.

All methods used for analysis have been tested using historical events, demonstrating the reliability of different detection techniques, such as the gray-level method and vibration analysis. The system was able to detect debris flow events with a detection time error of less than 1.3 seconds, while flow velocity measurements showed an average error of 7%. The estimation of flow depth achieved an accuracy within 5% of the manually traced values. These results confirmed the system's ability to detect debris flows with high precision, contributing to the development of effective warning criteria.

This system is mainly tested in Yu-Shui River area and Ai-Yu-Zi Creek. The stream is not very steep, but the weather is very humid and foggy. There was no false warning issued during heavy rainfall, heavy fog and earthquake less than 4 Richard scales. The performance of automatic judgement might be different in other extreme weather conditions. It needs more severe tests to ensure its performance.

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