A Novel Hybrid-Powered Low-Cost System for Volcanic Hazard Detection

Yang, Ruixuan (School: Harrow International School Beijing)

Volcanic eruptions pose severe risks to human lives, infrastructure, and the environment, affecting 500 million people worldwide. Early warning can reduce fatalities by 60%, yet 80% of 1,500 active volcanoes lack proper monitoring. Existing solutions rely on costly infrastructure, unstable power supplies, and require frequent maintenance, making them inaccessible in remote or low-resource areas. This study addresses these challenges by developing a hybrid-powered, low-cost sensor system for real-time volcanic hazard detection. The system integrates solar panels as the primary energy source with thermoelectric generators (TEGs) for supplementary power, ensuring continuous operation. Equipped with seismic, gas, and sound sensors, the system transmits real-time data via LoRa communication. Field studies at Inner Mongolia's Wulanhada volcano site validated the hybrid power approach. Laboratory tests confirmed: (1) reliable monitoring and data transmission, (2) an 11% power gain from TEG integration, and (3) sufficient power generation under normal sunlight but inadequate performance at night due to TEG limitations. To address this, a rechargeable battery provides up to 2.67 days of backup power, and an intermittent operation mode conserves energy during extended low-generation periods. Cost analysis shows that the system is affordable at $180 per unit, just 1-3% of traditional solutions, with a modular and lightweight design for easy deployment in rugged terrains. This research presents a scalable and sustainable solution for volcanic monitoring, enhancing early warning capabilities in resource-limited areas. By overcoming power and cost constraints, the hybrid-powered device offers a practical approach to mitigating volcanic risks.

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