

# Low-Cost, Open-Source Video Inclinometer for Sustainable Geodetic Monitoring

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## SUMMARY

The paper presents a newly developed digital video inclinometer designed for high-precision tilt monitoring in engineering and geodetic applications. The instrument employs a standard cylindrical spirit vial (30" sensitivity, 64 mm length) as the sensing element and a widely available low-cost digital camera module (ESP32-CAM with OV2640 sensor, 1600×1200 pixels) as the detector. Despite its low-cost hardware, the system achieves performance comparable to the commercial Leica Nivel 220—while costing less than €100.

Tilt estimation is performed using a combination of predictive features: the brightness-weighted centroid of the bubble, its geometric dimensions (length, width, area), and brightness gradients near the vial edge—all extracted via an open-source computer vision pipeline based on OpenCV.

Current performance shows angular errors of  $\leq 2''$  over 0–200",  $\leq 10''$  over 200–350", and  $\leq 20''$  up to 600" of tilt, achieving an operational range comparable to that of high-end commercial inclinometers ( $\pm 600''$ ). This extended range is primarily enabled by photometric features—especially brightness gradients near the vial boundary—which become highly sensitive as the bubble approaches the edge of the ampoule.

All software is open-source, promoting reproducibility and adaptation in resource-constrained settings. The sensor can be used for permanent stability monitoring of dams, bridges, landslides, and permafrost-affected infrastructure—particularly in developing regions or remote Arctic environments. The proposed high-precision inclinometer design can serve as a new component of low-cost geodetic sensor systems, become a part of collocated instrumentation in geodetic networks, and help make geodetic monitoring widely accessible.