Installation Process

The installation of the system involves setting up both the hardware and software required for sensor communication, data acquisition, and processing. The system is comprised of two modules with different sensing capabilities, an in-place inclinometer prototype and a small module equipped with a LiDAR sensor and an accelerometer, a Raspberry Pi 5 and a laptop.

The low-cost inclinometer (IPI) prototype developed by LNEC consists of four nodes comprised of an ADXL345 accelerometer and an ESP8266 microcontroller, encapsulated in a metal tube. The nodes communicate wirelessly with the central system and can be powered individually. The IPI is designed to monitor tilt or deformation along a structure.

The second module consists of an ESP32 microcontroller connected to a TFmini LiDAR sensor and an MMA7660FC accelerometer. This module complements the IPI by providing environmental context and capturing external physical disturbances.

A Raspberry Pi 5 is used as the MQTT broker host, serving as the central piece of the system’s communications. All data gathered is published on the broker under specific topics and, following a consistent approach across all components, instructions are computed based on the data and published on the broker, updating the system’s behavior. The Raspberry Pi is configured with Raspberry Pi OS and the Mosquitto MQTT broker, which is registered as a service to ensure it runs on boot.

For data storage, a Docker container stack is deployed on an external server or machine. The containers are managed using a Docker-compose file and, for this project, the stack comprised an InfluxDB instance, Grafana for data visualization and dashboard building, and Telegraf to fetch and aggregate data published on the broker. To ensure the data persists, a volume was created on the host machine. For a simpler setup, the data can be analyzed on InfluxDB’s web interface, however the dashboard creation is slightly more limited.

To process the data and support the dynamic behavior of the system, a Python script was developed. It implements a state machine and its transitions are triggered based on the difference between consecutive readings or the . All sensors contribute to these calculations and by transitioning between states the script updates the rate at which the inclinometer gathers data. The other sensors’ data acquisition frequency is also adjusted autonomously by the script, however they’re not tied to the state machine, so that the modules can evolve separately.

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Depending on the test setup, the IPI can be installed either as a complete unit or using just one of its four nodes. The only difference lies in the physical assembly, as all nodes connect wirelessly and automatically to the other components, and power can be supplied to any node individually. Additionally, some test environments may not support the simultaneous use of both the IPI and the distance-vibration module.

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For the development and testing of the monitoring system proposed, the test setup consisted of simulating a model scale dam using a water reservoir to evaluate the behavior of the IPI system under dynamic conditions. It involves a single IPI node mounted on a rotating support, influenced by the water level inside a container with a bottom-mounted tap. As water is released or added to the reservoir, the float mechanism causes the inclinometer to tilt, simulating gradual movement. The LiDAR sensor mounted above the tank measures the distance to the water, while the accelerometer detects vibrations. The experiment is divided into controlled phases, including tap closed (stable tilt), half-open, and fully open, to simulate different drainage rates. The goal is to assess data integrity, sensor interaction, sampling rate adaptation, and the reproducibility of system responses under varying water volume change rates.