Towards a Fully Open Seismometer Network: Expanding Free and Open-Source Seismic Monitoring Tools through Modular Hardware-Software Integration

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Introduction

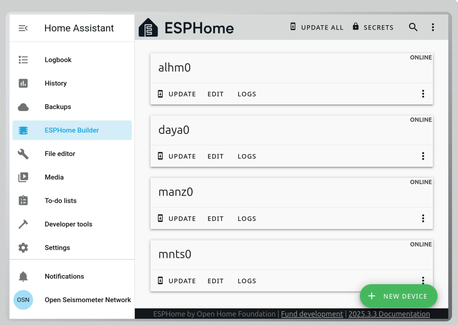
Seismic networks are fundamental tools for monitoring earthquakes, understanding the Earth's internal structure, mitigating seismic hazards, and enabling rapid responses to potentially destructive seismic events. Despite their importance, the expansion and density of these networks have often been constrained by the significant cost associated with professional-grade seismic instrumentation. This limitation particularly affects developing countries with limited economic resources. An additional challenge lies in the maintenance of diverse seismometer designs within a network, which frequently necessitates costly on-site visits for essential tasks like software updates or calibration. Addressing these limitations is crucial for advancing seismic monitoring capabilities globally.

Methods

To overcome the challenges of cost, proprietary limitations and maintenance difficulties, we present the Open Seismometer Network as a robust, low-cost alternative that enhances traditional open-source seismic monitoring approaches. This solution expands recent advancements in open-source management platforms with our novel Open Seismometer hardware design. The core methodology focuses on a modular hardware-software integration approach to streamline network deployment and simplify long-term instrument maintenance. The network architecture is built entirely on Free and Open-Source Software (FOSS) components. Specifically, the Open Seismometer design employs ESPHome for efficient low-level data acquisition. Secure connectivity for each network node is established using WireGuard VPN. Data distribution and processing are managed by the industry-standard tools RingServer and SeisComP.

Figure 1. Central server hardware-software management layers.

At the core of each Open Seismometer Network deployment is a central server running Home Assistant (an expandable system for sensor control). Plugins within Home Assistant expand the necessary functionality: Hardware is managed at a higher level with ESPHome, remote communications are secured with VPN Wireguard, and MSEED seismic records are received with a custom RingServer plugin.

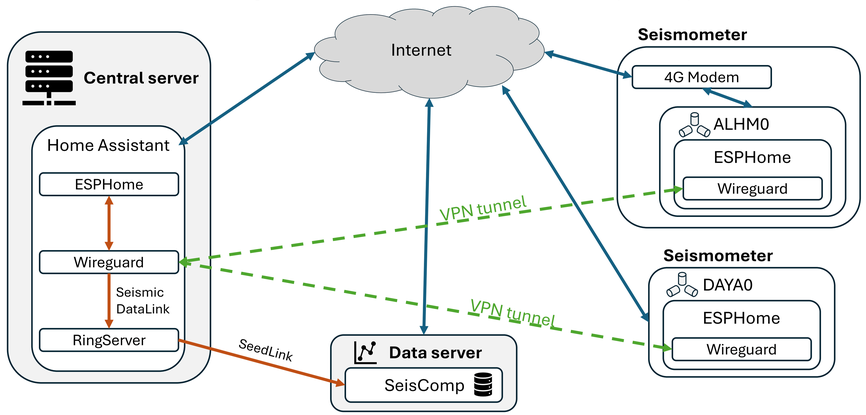


Remote management, including updates and reconfiguration, along with the visualization and storage of contextual sensor data for site monitoring, is facilitated through an additional layer leveraging Home Assistant. A key component of the methodology is the Open Seismometer design itself, which utilizes advanced period extension techniques applied to standard short-period geophones to achieve a better sensitivity.

Results

The implementation of the Open Seismometer Network architecture results in a highly effective and streamlined seismic monitoring solution. The integration of FOSS components ESPHome, WireGuard, RingServer, SeisComP, and Home Assistant enables fully remote management, reconfiguration, and updating capabilities for the network nodes.

The proposed architecture consists on a Central server (Figure 1) a Data Server (Figure 2) and Seismometer sensors (Figure 3) interconnected by standard-and-expanded protocols:



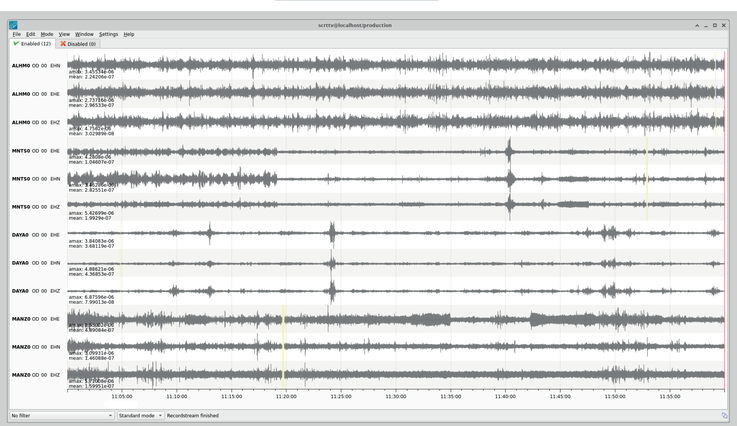


Figure 2. Data server running SeisComP seismic monitoring software layer. SeisComP is used for final data retrieval and archival, event detection, phase picking and monitoring the overall health of the seismic network. This figure shows the resulting real time stream of some of the stations in the network.

Another significant result stems from our Open Seismometer design; the application of advanced period extension techniques successfully enhances the response of standard short-period geophones. This effectively extends their detection capabilities into the lower frequency domain, achieving a sensitivity level comparable to more expensive broadband instruments. Consequently, the system demonstrates the capability to detect not only local but also regional and teleseismic events. The combination of traditional seismic software, open home sensing infrastructure, and the high-sensitivity, low-cost seismometer design enables highly effective seismic deployments.

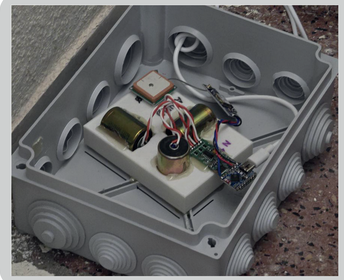


Figure 3. Open Seismometer signal capture layer.

Three geophone transducers capture earth's motion in ENZ axes while implementing electronic period extension and amplification. Its other tasks include analog-to-digital conversion, high-resolution oversampling, filtering, GPS timestamping, and MSEED conversion.

The core microcontroller is an ESP32 which allows streamlined WiFi communications, and the hardware programming is managed by ESPHome seen in Figure 1. Seismic data is then transferred over the network and is finally stored/processed with SeisComP as seen in Figure 2.

Conclusions

The Open Seismometer Network represents a significant step towards more accessible and adaptable seismic monitoring by integrating a novel, sensitive, low-cost Open Seismometer design with a fully Free and Open-Source Software stack for data acquisition, secure communication, processing, and remote management. This approach successfully addresses the limitations of high costs, proprietary restrictions, and complex maintenance associated with traditional seismic networks. The system achieves sensitivity comparable to broadband instruments through innovative period extension techniques, enabling comprehensive event detection. We believe our FOSS-based modular implementation offers a viable path to enhance seismic network density and performance globally.

References

- Home Assistant: https://www.home-assistant.io/
- ESPHome: https://esphome.io/
- RingServer: https://github.com/EarthScope/ringserver
- WireGuard: https://www.wireguard.com/
- SeisComP: https://www.seiscomp.de/

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You can contact us at https://github.com/OpenSeismometer/