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Earthquake Early Warning System based on 3 seconds of P wave: a Machine Learning approach for rapid detection, estimation magnitude and location

Pablo Lara ^{1,2}, Quentin Bletery ¹, Jean-Paul Ampuero ¹, Adolfo Inza ², Hernando Tavera ²

¹ Université Côte d'Azur, IRD, CNRS, Observatoire de la Côte d'Azur,
Géoazur, France

² Instituto Geofísico del Perú,
Lima, Perú



Introduction

Large, historical earthquakes on the Peruvian subduction fault have left signs of strong shaking with catastrophic scenarios. Seismogenic zones of Peru were identified offshore along the west coast, many cities that host thousands or millions of inhabitants located between 80 and 200 km from epicenters are more prone to strong shakes from earthquakes. In this context, Peru started the Seismic Alert System of Peru (SASPe) project, which consists of more than 100 accelerometric stations located on the Peruvian coast, in order to create an Earthquake Early Warning System (EEWS). SASPe, uses a minimum of 3 seconds of P wave signal coming from a single station to detect and estimate the magnitude and location of earthquakes. Obtaining these informations as fast as possible after an earthquake has started is critical to alert the population and stop infrastructures at risk.



Figure 1: SASPe stations.

We built an exhaustive database of waveforms by compiling the catalogs of Peru, Chile, Japan and the STanford EArthquake Dataset (STEAD, Mostafa et al. 2019). We selected events with magnitudes greater than 3, epicentral distance less than 200 km, and depth less than 100 km.

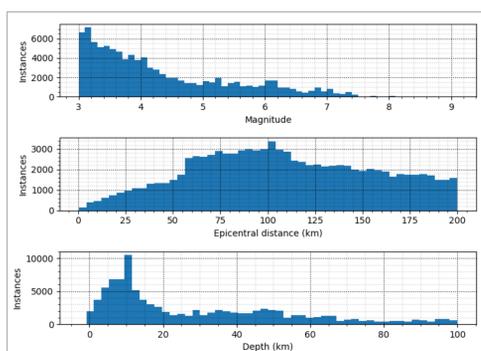


Figure 2: Histograms of magnitude, epicentral distance and depth of the database.

Magnitude and location predictions.

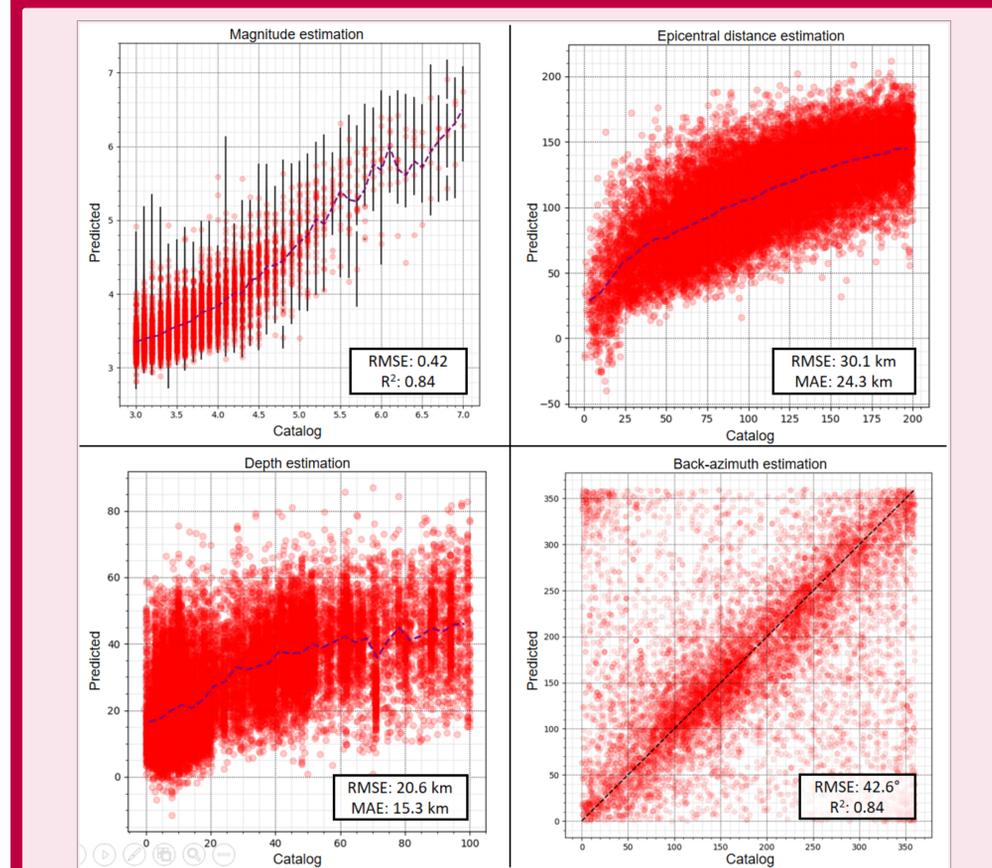


Figure 5: Results of the magnitude, epicentral distance, depth and back-azimuth estimates. All the results are obtained with only 3s of P-wave on a single-station.

Methodology

The present investigation is based on the Machine Learning (ML) algorithm, Extreme Gradient Boosting (XGB), which is fed by the feature vector extracted from the temporal, spectral and cepstral domains of the 3C seismic signals. 54 attributes are extracted per channel, generating a 162-dimensional feature vector. In the case of the back-azimuth problem, 10 more attributes are added associated with the polarization of the triaxial signal. The attributes are extracted from deconvolved signals, and the best results were found applying a band-pass filter from 1 to 7 Hz for the design of the detector and picking model, and from 1 to 45 Hz for the magnitude, epicentral distance, depth and back-azimuth.

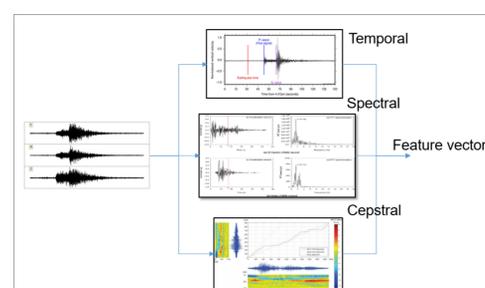


Figure 3: Feature vector generator extracted from the signal of a 3C sensor.

Results

The results of the models are shown in Table 1 and Figures 4 and 5. Figures are based on Hold-Out validation (80% training, 20% test) with only 3s of P-wave on a single-station.

Overall (%):	True class	
	Noise	Earthquake
99.91		
Predicted	Noise 100233	Earthquake 139
class	Earthquake 37	97891
Accuracy (%):	99.96	99.86

Table 1: Confusion matrix between noise and earthquake classes, using 10-Fold validation.

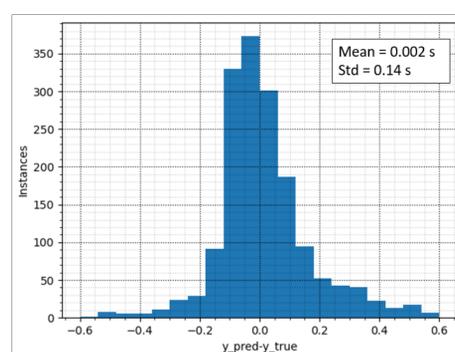


Figure 4: Histogram of the error in the P-phase picking.

Real-time scenario

The Instituto Geofísico del Perú (IGP), has started the construction of the stations corresponding to SASPe project, these are very close to the Peruvian coast. Each station has a strong motion triaxial accelerometer and a raspberry Pi 4, in the latter, the Machine Learning models are being installed, with the aim that only the alert message travels in the telemetry system and thus save valuable time that it can be used in the mitigation process.



Figure 6: Bayovar station, Piura, Peru.

The following figure shows the real-time detection, picking and the magnitude estimation, of an earthquake in Lima of magnitude 6.1 as cataloged by the IGP, using the models designed and installed in the Morro Solar station, which is located 90 km from the epicenter. The magnitude estimate using our ML algorithm was 6.17.

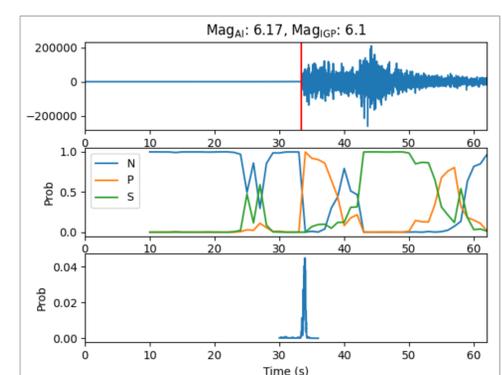


Figure 7: Real-time detection, P-phase picking and magnitude estimation of the earthquake in Lima of Magnitude 6.1, on July 8, 2021.

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