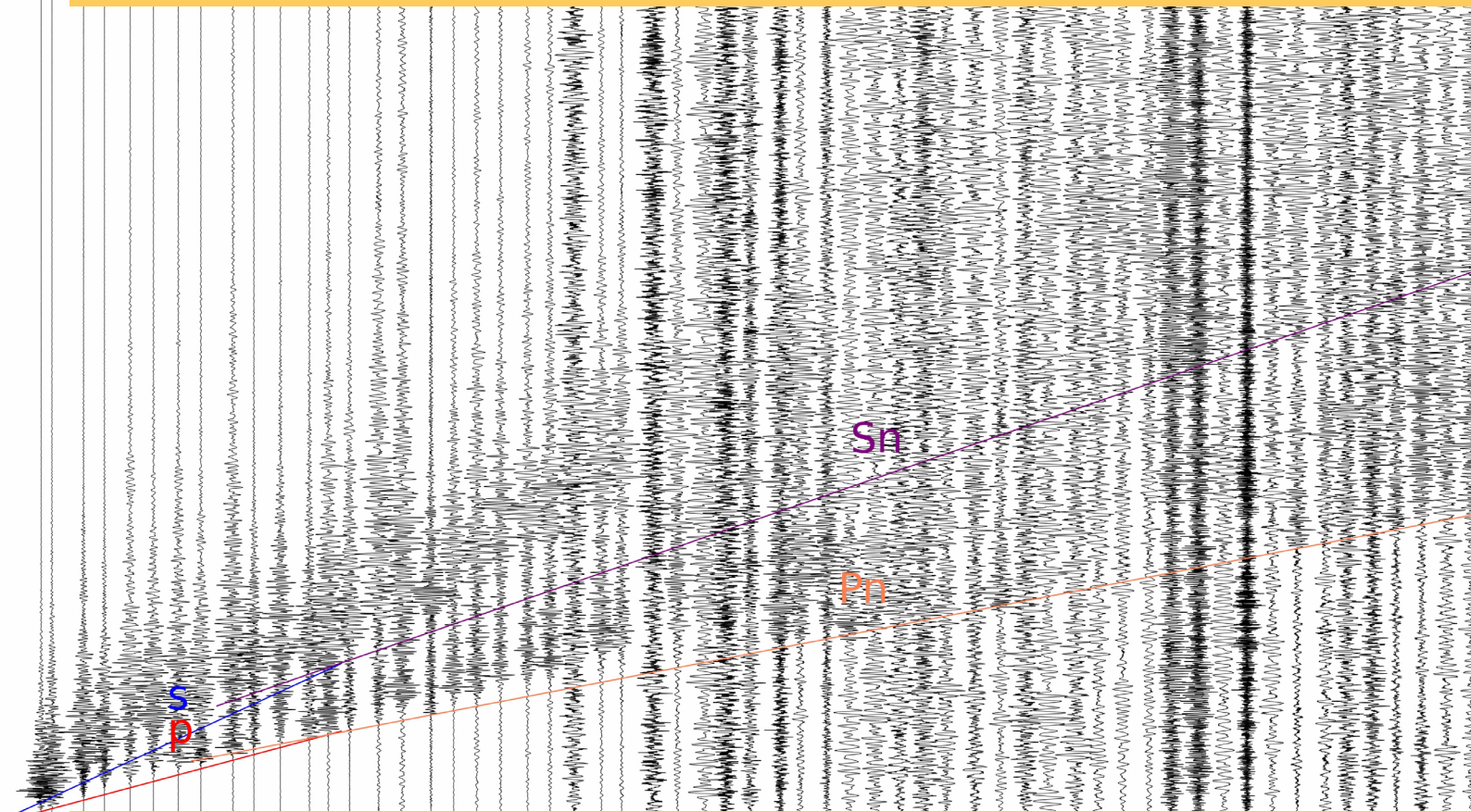




RAPPORTI TECNICI INGV

NMXP2MSEEDpy: a Python-based
software to convert data from the
Nanometrics Libra system to
miniSEED format



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NMXP2MSEEDpy: a Python-based software to convert data from the Nanometrics Libra system to miniSEED format

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Cover Graph of the seismic traces of the stations used for the location of the seismic event Mw 3.6 occurred at 06:33:05 UTC on December 9, 2024, in the area 3 km NW Roccamonfina (CE), Italy | In copertina Grafico delle tracce sismiche delle stazioni utilizzate per la localizzazione dell'evento sismico di magnitudo Mw 3.6 verificatosi alle 06:33:05 UTC del 9 dicembre 2024 nell'area a 3 km a nord-ovest di Roccamonfina (CE)

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Abstract

The primary aim of this technical report is to present NMXP2MSEEDpy, a free open-source software based on Python programming language. NMXP2MSEEDpy allows the conversion of the data stream from the NMXP format, used by the Nanometrics Libra instrumentation, to miniSEED data format. The main goal was to create a system that could rehabilitate the use of Nanometrics Libra instrumentation, which although dated, is still fully functional and performing, but is now being decommissioned also due to the obsolescence of the proprietary Nanometrics software used for the acquisition and storage of seismic data.

For this reason, it was decided to use the miniSEED format for data management. In fact, it is currently fully supported by the most used data acquisition, storage and processing software used in the seismological field. In the first part of this work, the hardware and software components of the Nanometrics Libra system will be examined in detail. This will be followed by a description of the NMXP2MSEEDpy software, focusing on its integration into a complete system for the management and distribution of seismic data, installed on dedicated hardware for remote on-site deployment. Finally, the installation carried out at an operational seismic station under real environmental conditions will be described, along with the seismic monitoring results obtained following this software upgrade.

Keywords NMXP2MSEEDpy; Nanometrics Libra System; NMXP data format

Introduction

The Libra Very Small Aperture Terminal (VSAT) system, produced by Nanometrics [1] (accessed on 16 April 2025), was developed to acquire seismic data from remote stations considered unreachable by other means of communication. The system is based on a combination of hardware and software components. Specifically, the hardware of a typical remote seismic station includes a variable number of digitizers, known as Trident, connected to a transceiver called Cygnus, and an antenna operating in the Ku-band (12-18 GHz) for satellite transmission. One of the key features of the Libra system is its straightforward installation and low power consumption. Furthermore, due to its reliance on satellite communication, it can be deployed at any remote location with satellite visibility. At least one network device is necessary for the connection between the various clients (remote stations) and the local server, referred to as the HUB, to ensure communication with all remote stations and to receive seismic data from them (Figure 1).

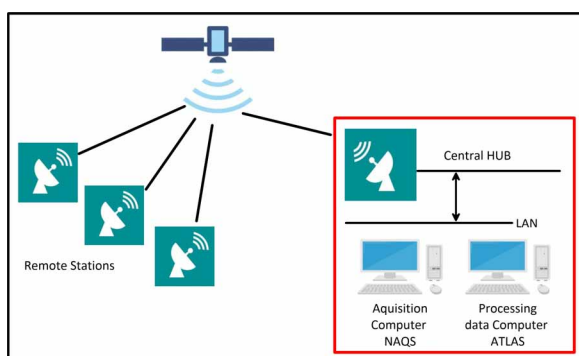
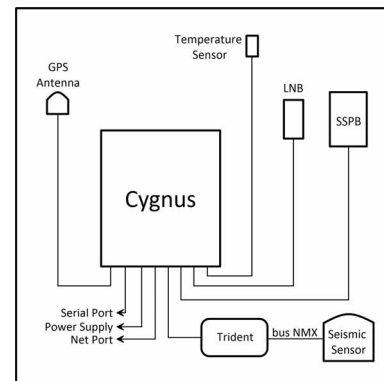


Figure 1 Simplified diagram of the satellite transmission and data management system of the Nanometrics Libra remote seismic stations.

In Figure 2, the hardware components of a Nanometrics Libra remote station are illustrated.

Figure 2 Schematic of the components of a remote seismic station with Nanometrics Libra hardware components: Solid-state Power Block-upconverter (SSPB) and Low Noise Block-downconverter (LNB).



The Cygnus data transceiver incorporates the satellite transmission component, while the digitizer, Trident, is external to the transceiver and connected via the proprietary NMXbus. Beyond the hardware devices in the seismic data acquisition chain, the proprietary software components from Nanometrics, known as Servers, are present: NaqsServer and DataServer. These software components manage the collection, distribution, and storage of seismic data. NaqsServer is the main management software, handling real-time data streams transmitted from remote seismic stations to the reception HUB, where they are stored in a ring buffer. DataServer accesses this buffer for data distribution to other Nanometrics software, such as ATLAS for seismic data analysis.

While the communication protocols used by the Nanometrics Libra system, such as TCP and UDP, are standard, the data format, NMXP, is proprietary. Consequently, interaction with the real-time data stream from the stations and subsequent seismic data gathering processing and storage can only occur through Nanometrics servers and others Nanometrics software.

This requirement to use proprietary software makes the Nanometrics Libra system a closed solution, limiting integration with other real-time seismic data management software, including third-party applications.

To address this limitation, tools such as nmxttools [2] (accessed on 16 April 2025) and nmxtptool [Quintiliani, 2007] were developed to act as interfaces between Nanometrics Servers and widely used seismological applications. These tools enable integration with software for seismic data analysis, such as SeisComP [3] (accessed on 16 April 2025) and Earthworm [4] (accessed on 16 April 2025), or for waveform visualization, such as Seisgram [5] (accessed on 16 April 2025) and Swarm [6] (accessed on 16 April 2025).

However, these interface tools remain dependent on the presence of the Nanometrics Servers, making them essential for data extraction, including in real-time applications.

In recent years, seismological monitoring has also benefited from technological evolution, which has opened new perspectives in data transmission management. The adoption of alternative communication platforms (Wi-Fi, 3G, 4G, LTE, new satellite systems, etc.) and the spread of seismic acquisition systems based on standard protocols, such as SEEDLink [7] (accessed on 16 April 2025), have created the possibility of using and disseminating new software platforms for managing seismological data, including open-source ones, capable of covering the entire life cycle of seismological data, from acquisition to processing and storage.

Nanometrics has followed this trend by developing new hardware systems, such as the Centaur digitizer system, which comply with scientific community standards by integrating an onboard SEEDLink server.

As a result, Nanometrics Servers have become obsolete and are no longer supported. Although Nanometrics has released firmware updates over the years to implement SEEDLink onboard for

older instruments, such as the Taurus data logger, no such update was provided for the Libra system. Consequently, the increasing adoption of new data digitizers based on standard protocols and the challenges associated with managing Nanometrics Servers have led to the gradual decommissioning of the Libra system. In most cases, this decision is not due to hardware malfunctions or hardware obsolescence, but rather to management difficulties related to proprietary software and data format constraints.

To eliminate the dependency on Nanometrics Servers caused by the use of the proprietary data format NMXP, NMXP2MSEEDpy has been developed. This aims to maintain the usability of the Libra instrumentation, which remains reliable and performs effectively despite in time.

The developed software enables the conversion of NMXP data streams into the miniSEED format and therefore the possibility of integrating a SEEDLink server, making the Libra station as system equipped with a native SEEDLink server on board and therefore compatible with modern seismic instrument.

As previously mentioned, other interface solutions with Nanometrics Servers exist for the data extraction. However, NMXP2MSEEDpy introduces two significant innovations compared to existing tools (e.g., nmxp2tool):

1. NMXP2MSEEDpy runs on dedicated hardware directly interfaced with the Libra instrumentation, meaning it operates at the remote station itself.
2. It is completely independent of Nanometrics Servers, thereby eliminating reliance on these servers for data stream management. This allows seismic data processing software, including open-source solutions, to be used downstream of the hardware instrumentation.

Figure 3 provides simplified diagrams comparing the Nanometrics Libra system (left) and the NMXP2MSEEDpy-based system (right). The figure illustrates the main differences between these approaches, and how the use of NMXP2MSEEDpy modifies the seismic signal acquisition chain at a remote station.

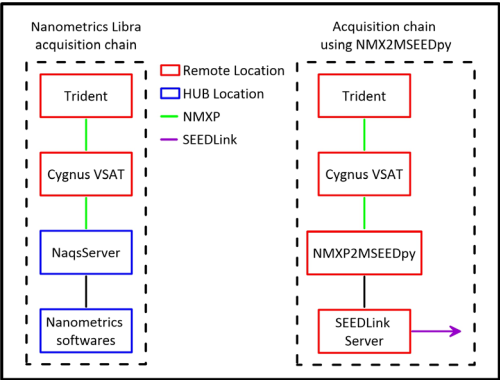


Figure 3 Diagram of the acquisition chain of the Libra Nanometrics system on the left. On the right, acquisition chain using the NMXP2MSEEDpy.

This work will not only describe the NMXP2MSEEDpy but also present a possible solution for its integration into a dedicated hardware system, aiming to create a complete platform for seismic data acquisition and distribution.

1. Nanometrics Libra system

This chapter provides an overview of the hardware and software components of a complete Nanometrics Libra seismic data acquisition system. A detailed description of the hardware used for data acquisition from the seismic sensors and for data transmission will be provided. The software section will focus on the structure of the NMXP data format adopted by the

Nanometrics Libra system and a description of the NaqsServer software. Special emphasis is placed on the NMXP data format, as it represents the target input of the NMXP2MSEEDpy used to convert the data to the miniSEED format.

1.1 NMXP data format

NMXP is a proprietary data format used by the Nanometrics Libra system. This format packages data for transmission via various protocols, including serial, UDP, and TCP. A fundamental requirement for the proper functioning of the NMXP format is an accurate time source, which ensures precise timestamping of data and its corresponding packets before transmission. An accurate time stamping of the seismic data is fundamental for their correct use in their processing phase (e.g., seismic event localization, etc.)

The transmitted data by a Libra system can be divided into two categories:

- Seismic data acquired in raw format from individual seismic channels.
- Instrument state-of-health (SOH) data.

Both categories undergo a timestamping process and are divided into data units called “bundle” each with a fixed length of 17 bytes. A bundle is an independent data collection unit, and multiple bundles form a data packet, whose length varies depending on the number of bundles it contains. A typical seismic data packet in raw format consists of:

1. An initial 4-byte section containing information about the oldest available packet in the data stream.
2. A first bundle known as the packet header.
3. An odd number of “n” bundles containing seismic data. The number of bundles is set within the Trident digitizer according to specific needs.

The total packet size (in bytes) is calculated as follows:

$$\text{Packet size} = 4 + 17 + (17 \times \text{number of bundles})$$

The packet header bundle includes an essential timestamp and an ID code that identifies the instrument type (e.g., Cygnus, Trident, etc.). It is followed by another bundle, the compressed data packet header, which contains key values such as:

- The timestamp of the first raw data value in the packet.
- The sampling frequency.
- The instrument ID (serial number).
- The first sample value, stored as a 24-bit signed integer.

Subsequently, “n” data bundles follow, each containing raw seismic data from a specific channel, stored in a compressed format. The compression algorithm uses a first-difference algorithm, allowing each data bundle to store between 4 and 16 raw seismic data samples. SOH data are transmitted using the same technique, with packets composed of multiple bundles. For further details on the NMXP data format, please refer to the official Nanometrics documentation [Nanometrics Inc., 1996–2003].

1.2 Cygnus transceiver

The Cygnus system is a transceiver that allows data transmission via multiple channels, including

satellite communication through an integrated satellite modem, as well as local Ethernet and serial port. Seismic data digitizer devices communicate with Cygnus via Nanometrics' proprietary serial interface, known as NMXbus. This bus has a dual purpose: providing both data communication and power supply between Cygnus and digitizers (e.g., Trident). A key advantage of the NMXbus is its ability to connect multiple devices in series using a single communication line. For instance, up to three Trident units can be connected in series, allowing the system to transmit data from up to nine seismic channels simultaneously. The timestamping of packets is managed via a GPS receiver using the TimeServer software. Some older Cygnus units were affected by the GPS Week Rollover issue [Langley, 1998]; however, newer models continued functioning correctly after the most recent GPS epoch transition. A simple hardware modification can fully restore the time synchronization functionality for affected units [Nanometrics, 2018]. The Cygnus system can be configured and monitored through the Nanometrics User Interface (UI). For further details on the Cygnus system, please refer to the Cygnus transceiver manual [8] (accessed on 16 April 2025).

1.3 Trident digitizer

The Trident is a 24-bit digitizer with a total dynamic range of 142 dB. Each Trident unit supports up to three seismic channels. It connects to data transmission devices (e.g., Cygnus) via the NMXbus, which provides both power and data communication. Specifically, the NMXbus transmits raw data from individual seismic channels and ensures precise time synchronization for data tagging. Additionally, it enables configuration of the front-end system through the Nanometrics UI. This versatility allows Trident to support a wide range of seismic sensors. Trident is designed with a highly durable structure, making it suitable for outdoor installations. The NMXbus connection also enables multiple Trident units to be daisy chained. In terms of digitization, Trident supports sampling rates from 10 to 1000 samples per second (sps). It incorporates digital filters, including Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters, to process the acquired data. The interface software provides functions such as system monitoring, analog input of digitizer configurations, firmware updates, and sensor control (e.g., mass position control). Furthermore, Trident supplies DC power to sensors, offering various voltage output options. The raw data from Trident is transmitted via NMXbus to the transmission system (e.g., Cygnus), which then forwards it in NMXP format to the remote-control system (e.g., NaqsServer). For further details on the Trident digitizer, please refer to the Trident manual [9] (accessed on 16 April 2025).

1.4 NaqsServer

Nanometrics' NaqsServer software is designed to acquire and store data from Nanometrics hardware devices, such as the Cygnus transceiver, using the NMXP protocol. It stores this data in a ring buffer, which enables other software applications to process and visualize the data. Furthermore, NaqsServer supports automatic recovery of lost or corrupted data by requesting the retransmission of packets that were affected during the initial transfer. The system operates based on channel telemetry, meaning that each seismic component, or channel, is acquired and archived separately. Since NMXP data packets include metadata specifying the source channel (as detailed in Paragraph 1.1), no additional routing is necessary before storage or processing; packets are archived correctly using their embedded metadata. NaqsServer handles both seismic data and SOH data. It is compatible with multiple operating systems, including Linux and Windows, and requires a Java Runtime Environment (JRE). For further details on the NaqsServer, please refer to the NaqsServer manual [10] (accessed on 16 April 2025).

2. SEED data format

The Standard for the Exchange of Earthquake Data (SEED) [11] (accessed on 16 April 2025) is the internationally recognized format for exchanging digital seismological data, as well as any digital data acquired at regular time intervals. The full SEED format includes both metadata and time-series data. SEED is highly flexible, allowing for different subsets of the format:

- Dataless SEED contains only header metadata volumes and no time-series data.
- miniSEED volumes store only time-series data with minimal metadata. A miniSEED file or stream consists of concatenated data records.

For further details on miniSEED, refer to the official documentation [12] (accessed on 16 April 2025).

3. NMXP2MSEEDpy software

The NMXP2MSEEDpy software, developed using the Python programming language [13] (accessed on 16 April 2025), enables the conversion of data from the Nanometrics Libra system's proprietary NMXP format to miniSEED format. NMXP2MSEEDpy implemented several Python libraries, among which of fundamental importance ObsPy [14] (accessed on 16 April 2025). ObsPy is an open-source Python library specifically designed for processing seismic data and metadata [Beyreuther et al., 2010]. It implements numerous functions that facilitate seismic data processing at all stages, including reading and writing in various standard formats (miniSEED, SAC [15] (accessed on 16 April 2025), etc.), as well as data processing and transformation (e.g., filtering, etc.). Specifically, version 1.4.1 of ObsPy was utilized in the developed software.

NMXP2MSEEDpy employs a multitasking architecture, enabling parallel execution of its core functions. These primary functions include:

- System time synchronization via GPS references extracted from the NMXP data stream at defined intervals.
- Reception of the NMXP data stream using UDP streaming.
- Decompression and parsing of NMXP data packets to extract both data and metadata.
- Creation and storage of data in miniSEED format files.
- Management of the miniSEED file queue.

All essential configuration parameters for NMXP2MSEEDpy's operation are defined within a text-based configuration file. An example of such a configuration file, in this example called *setting.txt*, is provided below.

```
#Seedlink#
network = XX
station = TEST

#IP Client address#
client_IP = 192.168.69.5
destination_port = 32000

#Serial Number of the connected Trident (insert the S/N in ascending order)#
S/N_trident = 659,718

#List the Tridents in ascending order from the smallest serial number#
#S/N, Location Code, sps, Component Z, Component N, Component E#
trident1 = 659,00,100,HHZ,HHN,HHE
```

```

trident2 = 718,00,200,HNZ,HNN,HNE

bundle_length = 28

#miniSEED files directory#
files_path = /home/user/nmXP2mseedpy/mseed/

#miniSEED tail files#
files_tail = 30

#System time update#
time_update_seconds = 3600
timezone = "UTC"

```

The *setting.txt* file, which contains the configuration details, needs to be provided as a command-line argument when running the NMXP2MSEEDpy Python script. This allows the NMXP2MSEEDpy to correctly interpret the configuration information (e.g., the command for a Linux system is shown below).

```
python3 /path/to/NMXP2MSEEDpy /path/to/setting.txt
```

The *setting.txt* file contains all the necessary information for both the data stream communication and the metadata contained in the subsequent miniSEED files created.

In particular, the first two lines provide the network code and station code information, which will be inserted into the miniSEED metadata. Following that, there is the network information of the device to which the NMXP format packets sent by the Nanometrics server integrated into the Cygnus system are addressed, specifically the network address of the hardware client device on which the NMXP2MSEEDpy software is running. By default, port "32000" is used by the Nanometrics server for sending the NMXP data stream. The network values must also be correctly configured on the Nanometrics server integrated into the Cygnus and may therefore vary accordingly.

Next, *setting.txt* also includes details about the digitizers in use, such as serial numbers, location codes (which can be omitted if necessary while still maintaining the separator ","), sampling frequency, and the codes of the active channels.

A crucial parameter is the number of bundles sent by the acquisition systems. Ensuring its accuracy in both *setting.txt* and the acquisition modules (e.g., Trident) is essential for the proper functioning of the system. Following this, the file specifies the directory path where the miniSEED data files are saved, the maximum number of files allowed in that directory, and the settings for system time synchronization. The example insert above, provides a generic configuration file named *setting.txt*, which enables the correct reading of a data stream from two Trident units. This configuration can be easily adapted for use with more than two Trident systems by simply adding the necessary additional information. If the "#" symbol is placed at the beginning of a line containing data for a specific Trident, that line will be treated as a comment, effectively excluding that Trident from data acquisition.

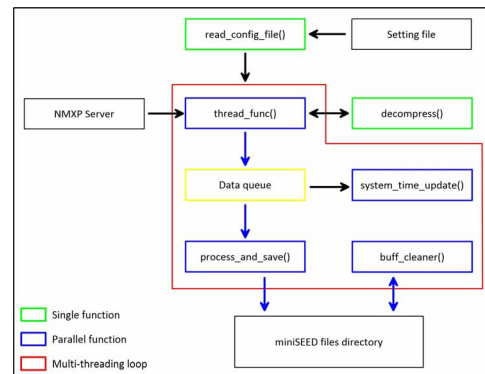
Editing the *setting.txt* file while the Python software is running does not affect its real-time operation. To apply any modifications, NMXP2MSEEDpy must be restarted with the updated *setting.txt* file.

Ultimately, the values specified in *setting.txt* do not directly alter the settings configured on the Nanometrics hardware; they must be set consistently to ensure proper operation.

Figure 4 presents a simplified schematic of the main functions implemented in NMXP2MSEEDpy and their interactions.

At each initial startup of NMXP2MSEEDpy, the *setting.txt* file is first read by the *read_config_file* function. The retrieved parameters are stored in variables that will be used by the implemented functions.

Figure 4 Simplified diagram of the operation of the NMXP2MSEEDpy software. In the diagram you can see the main functions implemented and the data flow between the functions themselves.



The continuous data stream from NaqsServer is read by the *thread_func* function through a Server-Client connection based on the UDP protocol.

From the data stream, both metadata and seismic sensor data are extracted, and decompression is applied. The decompression process is specifically handled by the *decompress* function, which is responsible for decoding the raw compressed data received from the acquisition systems.

Metadata and seismic data are then transferred to the *system_time_update* and *process_and_save* functions via a First In, First Out (FIFO) data transfer queue. The *system_time_update* function is responsible for periodically setting and updating the system time of the machine running NMXP2MSEEDpy. However, this function only sets the system clock of the hardware running the NMXP2MSEEDpy software; it does not influence the timestamping of seismic data, as the temporal reference for the data always comes from the time-tagging provided by the Time Server integrated into the Nanometrics system.

The system time update interval can be configured as needed and is specified in the *setting.txt*. The *process_and_save* function, on the other hand, processes the decompressed data and saves it in miniSEED format in the designated data storage directory.

Finally, the *buff_cleaner* function monitors and regulates the number of miniSEED files stored in the directory where these files are saved. The maximum number of files allowed in the storage directory is specified in the *setting.txt*. The oldest data files are always deleted first, ensuring that the device's storage does not become full and that a buffer memory is maintained. This buffer allows an external application, such as a SEEDlink Server, to read the data and store it in its own ring buffer.

A more detailed discussion of the integration of NMXP2MSEEDpy within a complete data management and communication system is provided in the dedicated application section of this work.

Although the NMXP2MSEEDpy software presented in this technical report is, at the time of its presentation, in a stable and tested version, and the reliability and accuracy of the converted data have been verified, it is still under development and, in keeping with the open-source philosophy, remains subject to potential modifications, improvements, and updates. Nonetheless, as with any software, bugs may still be present, and for this reason the tool is under continuous refinement and evolution.

All related materials, including the NMXP2MSEEDpy software, auxiliary files, and the user guide, are available to all users at the following repository <https://gitlab.rm.ingv.it/giuseppe.ruzza/nm xp2mse edpy>.

4. Application of the NMXP2MSEEDpy

To verify the proper functionality and stability of NMXP2MSEEDpy under real operating conditions, the software was integrated into a complete seismic data acquisition and distribution system. The hardware selected for this implementation had to meet specific operational requirements. Among these, low power consumption was a key factor, while still ensuring sufficient computational power for the proper execution of all necessary software routines.

A fanless mini-PC was selected with the following specifications: an Intel Celeron J4125 CPU, 8 GB RAM, and 128 GB SSD storage. Finally, Ubuntu 22.04.4 LTS [16] (accessed on 16 April 2025) was used as the operating system.

The total power consumption of the selected hardware configuration—including the computational load required to run all necessary software components—was approximately 3 W. The low computational demands of NMXP2MSEEDpy and other essential software (e.g., SEEDlink Server) enable the use of low-power hardware platforms, such as the Raspberry Pi [17] (accessed on 16 April 2025). In fact, a test conducted on a Raspberry Pi 4 demonstrated that its hardware was sufficiently powerful to support the proper execution of the entire implemented system.

For data distribution, the SEEDlink standard protocol was chosen. SEEDlink is designed to ensure reliable data transmission over the Internet or private TCP/IP-compatible networks. Its robustness lies in its ability to allow clients to disconnect and reconnect without data loss, as transmissions can be resumed as long as the data remains available in the server's buffer. This allows the server to retransmit missing data packets.

The requested data streams can be filtered by specifying the desired network, station, location, and/or channel. Each data packet consists of 512-byte miniSEED records.

SEEDlink operates through an initial ASCII command-based data selection phase, followed by the continuous transmission of data packets from the server to the client.

During negotiation, the client can request specific data streams identified by network and station codes. Additionally, SEEDlink supports two operational modes:

- Uni-station mode: Transmits a single data stream associated with a specific station without requiring additional client-side configurations.
- Multi-station mode: Allows the simultaneous transmission of multiple data streams from different stations through a single connection.

For implementing multi-station mode, the Ringserver software [18] (accessed on 16 April 2025), developed by EarthScope, version 4.0.0, was used.

Ringserver is a ring-buffer system designed for data streaming and supports multiple communication protocols, including DATAlink, SEEDlink, and HTTP/WebSocket.

The primary input data format for Ringserver is the miniSEED file. Data acquisition in miniSEED format can be performed in two operational modes:

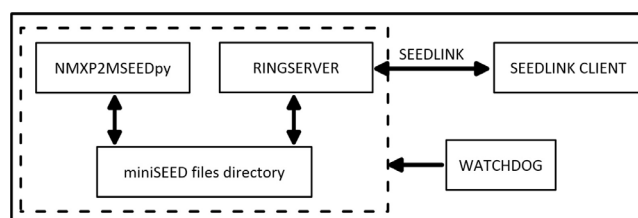
1. Scanning a target directory.
2. Direct data transfer via the DATAlink protocol.

Figure 5 presents a schematic representation of the implemented software system within the Ubuntu environment, highlighting its main components and their interactions.

In particular, the scanning mode of the Ringserver program was used. In this mode, a continuous scanning loop is active on a specified directory, which is the folder where the miniSEED files created by NMXP2MSEEDpy are saved.

This mode continuously reads all the miniSEED files present in the target directory. If it detects a file that is not already present in its ring buffer, it adds it to memory.

Figure 5 Simplified diagram of the software components and their interaction implemented in the dedicated hardware.



The number of files in the directory is managed by the *buff_cleaner* function (as described in Chapter 3). Controlling the number of files is crucial to prevent slowdowns caused by an excessive number of files being scanned by Ringserver, which could lead to potential issues or even system malfunction due to memory saturation.

Therefore, the number of files should neither be too high—causing slowdowns in the scanning process or memory saturation—nor too low, which could prevent Ringserver from acquiring data in a timely manner. Through a trial-and-error approach, a suitable number was determined—approximately 30 files—to ensure the proper functioning of the system.

Ringserver is also responsible for data distribution via the SEEDlink protocol to any requesting clients. The Ringserver software uses a text-based configuration file, which contains various settings essential for program operation, including key parameters such as:

- Ring-buffer depth.
- Acquisition mode.
- miniSEED file scanning directory

Additionally, a watchdog function has been implemented within the Ubuntu system. This function continuously monitors the proper operation of both Ringserver and NMXP2MSEEDpy. If one or both programs unexpectedly terminate due to any issues, the watchdog ensures their immediate restart.

As implemented, this function allows for the automatic startup of all necessary software for system operation whenever the host hardware is powered on. As soon as the device is turned on, it automatically launches Ringserver and NMXP2MSEEDpy in separate sessions using the Linux “Screen” function [19] (accessed on 16 April 2025).

Below is an example of the implemented watchdog function.

```

./etc/profile
export DISPLAY=:0.0

cd /home/cignus
var='ps auxw | grep ringserver | grep -v grep'
#echo $var
if [ -z "$var" ]; then
cd /home/cignus/ringserver
screen -S RINGSERVER -d -m ./ringserver config.conf
fi

cd /home/cignus
var='ps auxw | grep NMXP2MSEEDpy | grep -v grep'
#echo $var
if [ -z "$var" ]; then
cd /home/cignus/nm xp2seedlink
screen -S NMXP2MSEEDpy -d -m python3 NMXP2MSEEDpy.py setting.txt
fi

```

Figure 6 shows the wiring diagram of the hardware devices used to implement the data conversion system from NMXP Nanometrics to miniSEED using the NMXP2MSEEDpy software and transmission with the SEEDlink protocol. The figure also shows, for clarity, the data routing paths between the various devices.

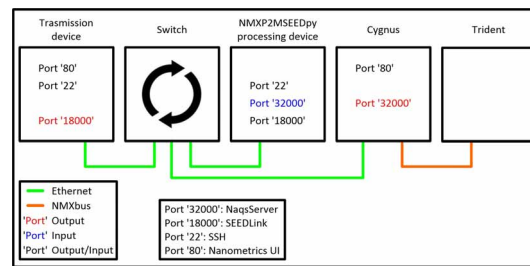


Figure 6 Connection diagram between the hardware devices used on a remote seismic station equipped with Libra instrumentation and the dedicated hardware for the implementation of the complete seismic data conversion and distribution system based on NMXP2MSEEDpy. The diagram also outlines the data routing scheme among the various devices. A network switch manages the routing of all data packets transmitted or received by the connected hardware components.

5. Site installation and monitoring results

After several months of successful laboratory testing of the complete data acquisition and distribution system, it was installed at a site of the National Seismic Network (In Italian: Rete Sismica Nazionale - RSN) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) [Michellini et al., 2016]. The selected station was PSB1, located in the Municipality of Pesco Sannita (BN), Italy (Figure 7).



Figure 7 On the left the photo of the new installation of the PSB1 station where it is possible to see the mini-PC (black device) installed on the Nanometrics Cygnus system, on the right the photo of the sensor well where the Trident digitization system and the two seismic sensors are installed, the velocimeter and the accelerometer.

The station has been active since March 1, 2003, and has been equipped with Nanometrics instrumentation since October 6, 2004. Specifically, the installed Nanometrics equipment includes a Cygnus acquisition system, Trident digitizers, and a Trillium 40 S broadband seismometer. Additionally, a Kinemetrics Episensor ES-T accelerometer is also installed.

The data transmission method for the PSB1 station has changed over time. From October 6, 2004, to September 20, 2017, data was transmitted using the Nanometrics satellite communication system. After that, the satellite system was decommissioned and replaced with a Wi-Fi-based transmission system [Cardinale et al., 2010].

Finally, on November 27, 2024, the newly developed hardware system described above was installed as part of major station maintenance.

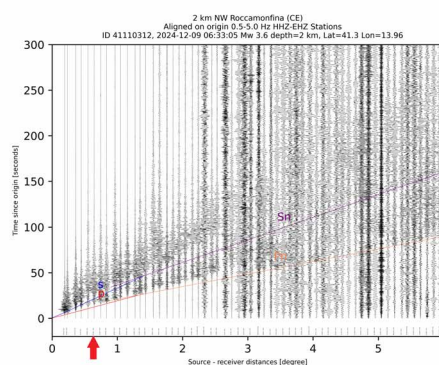
As a result, from October 6, 2004, to November 27, 2024, the station relied on the Nanometrics NaqsServer software system for remote data collection and storage. The newly implemented system, however, enables data conversion and transmission via the SEEDlink protocol,

simplifying the data acquisition process and eliminating the need for the proprietary Nanometrics NaqsServer system, which is now being permanently decommissioned due to obsolescence.

5.1 Localization of seismic events at PSB1 station

After installing the dedicated hardware running NMXP2MSEEDpy, the proper operation of the upgraded station was successfully verified. The new data conversion and transmission system using the SEEDlink protocol was confirmed to function correctly for seismic event localization. The first seismic event in which the signal from the PSB1 station, equipped with the new system, was successfully utilized occurred on December 9, 2024, at 06:33:05 UTC. This event was a Mw 3.6 earthquake with an epicenter 3 km northwest of Roccamonfina (CE), Italy, at coordinates 41.3050°N, 13.9560°E, and a depth of 2 km (Figure 8).

Figure 8 Graph of the seismic traces of the stations used for the location of the seismic event Mw 3.6 occurred at 06:33:05 UTC on December 9, 2024, in the area 3 km NW Roccamonfina (CE), Italy. The red arrow indicates the seismic trace of the PSB1 station (graph created by the RecSec web application [Palombo et al., 2022] [20] (accessed on 16 April 2025).



The successful localization of the seismic event, facilitated by the inclusion of the PSB1 station signal, further validated the effectiveness and reliability of the developed system.

Beyond confirming the accuracy of the data conversion performed by the NMXP2MSEEDpy software, an assessment was also conducted to evaluate the latency of the seismic signal between the station and the seismic surveillance room. The objective was to determine whether NMXP2MSEEDpy introduced any delays compared to the average latencies observed at other seismic stations.

The latency measurements - expressed in seconds - related to the PSB1 station, now operating with the NMXP2MSEEDpy-based system, showed no significant increase in transmission times. The observed latencies remained within the typical mean values for seismic stations utilizing a similar transmission vector and a native on-board SEEDLink server.

Conclusions

This technical report introduced NMXP2MSEEDpy, a Python-based software developed to convert data streams from Nanometrics' NMXP format to the widely used miniSEED format. This conversion facilitates the continued use and re-evaluation of Nanometrics' Libra instruments, which, despite their age, remain reliable and high-performance even after years of operation.

The adoption of NMXP2MSEEDpy eliminates the dependency on proprietary data management systems such as NaqsServer, which were essential for managing NMXP data streams. Nanometrics' server software is now obsolete, unsupported, and requires an outdated version

of Java, further complicating its use. The lack of updates and reliance on outdated technologies create significant obstacles for managing both the Libra software and instrumentation.

Additionally, NaqsServer introduces operational challenges by requiring dedicated hardware and requiring direct accessibility from remote stations, thus requiring firewall exceptions that expose the system to potential security risks.

In contrast, NMXP2MSEEDpy generates data in the miniSEED format, an open and standardized format that is fully compatible with the most widely used tools for seismic data acquisition, processing, storage and distribution. This ensures easy integration into existing workflows and systems within the seismic community.

In addition to presenting the NMXP2MSEEDpy, this report also described its integration into a complete seismic data management system that enables the acquisition, conversion and distribution of data from Nanometrics Libra remote stations, based on NMXP2MSEEDpy and other open-source software (e.g., Ringserver).

After extensive laboratory testing, the complete NMXP2MSEEDpy-based system was installed at RSN PSB1 for field validation. The successful testing confirmed the operational robustness and reliability of the system, as well as the quality of the collected seismic data, suitable for accurate earthquake localization.

Therefore, an upgrade of the Nanometrics Libra instrumentation with the NMXP2MSEEDpy software, within a complete data management and distribution system, would allow to re-evaluate the use of such instrumentation, both for those already present in the RSN seismic stations, and for new installations in experimental networks dedicated to data collection for scientific purposes or for monitoring the territory on a local scale, even temporary.

License

NMXP2MSEEDpy is licensed under GNU Lesser General Public (LGPL) v3.0.

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