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Design and Implementation of a Trigger Digitizer for Earthquake Monitoring System

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A B S T R A C T

One of the main devices in the earthquake monitoring system is the digitizer, which converts the analog signal to a digital one. We design and implement a trigger digitizer to store/transmit the seismic data. The implemented digitizer consists of several blocks, i.e., the power source, the front end circuit, analog to digital converter (ADC), GPS receiver, microcontrollers, microprocessor, and deep learning picking module. Besides, we use three finite impulse response (FIR) filters to decimate the sampling rate of the input seismic data. In addition, we utilize the CapsPhase network to pick the first arrival time of the earthquake. In this way, the digitizer is a trigger device, where an enable signal is released once the earthquake is detected to take the appropriate action.

1. Introduction

The development of seismic-sensing instruments had passed through different stages during the last eighty years. There are five major stages of development: the electron tube (optical spot recorders), transistors (analog tape recorders), conventional digital seismographs (digital tape recorders), the 16-bit seismographs, and the 24-bit seismographs [1], and the references included in it. There are hundreds of high-resolution digital seismographs that are manufactured in the market by many companies such as Nanometrics, Kinemetrics, RefTek, ION, Sercel, and many others [2-6]. These digital seismographs are targeting the detection of many kinds of seismic signals starting from passive, pico-, nano-, and micro- to strong seismic events. There are two broad classes of seismic waves, i.e., body waves and surface waves. Body waves travel within the body of Earth. They include P, or primary, waves, and S, or secondary, waves. P waves cause the ground to compress and expand, that is, to move back and forth, in the direction of travel. They are called primary waves because they are the first type of waves to arrive at seismic recording stations. P waves can travel through solids, liquids, and even gases. S waves shake the ground in a shearing, or crosswise, a motion that is perpendicular to the direction of travel. These are the shake waves that move the ground up and down or from side to side. S waves are called secondary waves because they always arrive after P waves at seismic recording stations. Unlike P waves, S waves can travel only through solid materials. After both P and S waves have moved through the body of Earth, they are followed by surface waves, which travel along Earth's surface. Surface waves travel only through solid media. They are slower-moving than body waves but are much larger and therefore more destructive.

The development of such seismographs is strongly connected with the continuous advances in seismic-data acquisition methods, together with many other technologies. These technologies may include; the progress in electronic technologies [7], seismic exploration updates, intelligent control, computer science, network topologies [8], Internet of Things (IoT) [9], signal processing [10], and many other disciplines [11-12].

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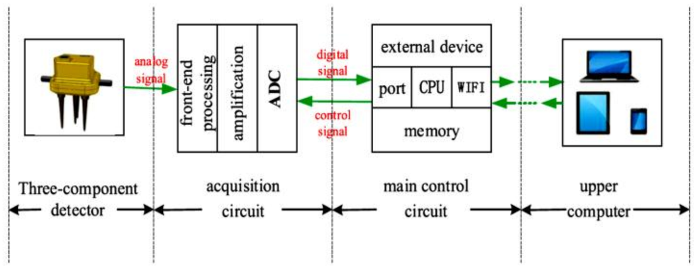


Figure 1 Block diagram of the Acquisition System [13].

The acquisition station is divided into three sectors, as shown in Figure 1, as follows:

1) High-sensitivity transducer, which converts the nano-seismic signal from the vibrational source into an electrical nano-signal.

2) The packets are stamped by time using GPS.

3) The controller, which archives the digital stream, uploads that stream to the computer, and then controls the acquisition station.

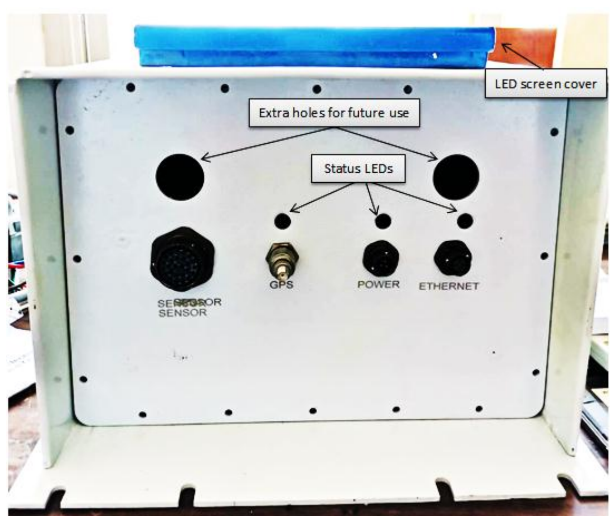


Figure 2 Seismic data monitoring system

In this work, we design and implement a trigger digitizer to convert the received analog signal into digital signal, store/transmit the digital signal, and detect earthquakes.

Figure 3 GPS receiver board and its U-Blox multi-band GNSS antenna.

2. Theory and Implementation

2.1. The Main Blocks

The basic building blocks of the seismic digitizer are the power source, the front end circuit, ADC, GPS receiver, microcontrollers, and microprocessor. Figure 2 shows the integration of these components together.

First of all, the seismometer is an instrument that responds to ground noises and vibrations such as earthquakes and explosions. We have been using three components sensor that detects three directions of earth movement. Secondly, the front-end circuit including the ADC (Analog to Digital Converter) is used to convert the analog signal from a seismometer to a digital signal for further processing and analysis. For controlling the NI 9229, a driver that controls the sampling rate and the acquired number of samples in LABVIEW had been built.

Thirdly, the GPS receiver provides the proposed system with time and location information. The location and timing information is very important to build the data header in SEED or MiniSEED format. The data is stamped with the time and location using the GPS device. The U-Blox ZED-F9P board is used for high data precision from the Global Navigation Satellite System (GNSS), as shown in Figure 3.

Fourthly, the GPS receiver information such as the number of satellites in view, latitude, longitude, date, and time are extracted using python code automatically. To stamp the location and timing information alongside the data header, we integrate the GPS information to the extracted data from the digitizer in the system block diagram via USB ports.

The Microprocessor is considered the main unit that connects and powers the front end circuit, GPS receiver, and Microcontroller with each other's using USB ports. The Universal Serial Bus (USB) is an interface through which information transfers in or out of our system consecutively. Controlling the seismic data monitoring system is done using the LABVIEW software which is installed in the Microprocessor. Moreover, archiving all data from our system is stored in the hard disk of the Microprocessor to make a handy data retrieval. In this phase, IW32 motherboard is used as microprocessor.

The data is acquired using the front-end circuit, (NI 9229). The ADC type is from Delta-sigma type. The 24-bit ADC in this circuit is used for converting the analog signal (from seismometer) to a digital stream. The acquired data is saved in ASCII file format with an arbitrary header (as described below). However, archiving and exchanging seismological time series data should be formatted according to one of the international standards which are not the same as the ASCII format extracted from NI 9229. One of the well-known standards is the Standard for the Exchange of Earthquake Data (SEED) format. SEED format contains time series data alongside the related station metadata. This Metadata is the network and station information, including the instrument response and the coordinates information. Most of the station metadata is approximately constant and unchangeable for long periods, therefore, the MiniSEED format contains only very limited metadata such as station code and sampling rate. So that, we start building the MiniSEED file and full SEED volume for our system.

The location and timing information are very important to create the data header in SEED or MiniSEED format. The metadata of our generated MiniSEED file is organized as standard rules rather than the random header of the ASCII file data. MiniSEED data format is used for constant data streaming because of the ability to construct a large amount of data by combining small packets together. Additionally, efficient data archiving rather than the complex structure of full SEED format.

The ASCII format is converted to MiniSEED format using Obspy [14] which is a Python framework for processing seismological data. The data stream in Obspy is defined using header. The header contains five main parameters: 1) network name, 2) station name, 3) channel name, 4) the used sampling rate, and 5) the stamped date and time of the first data sample. Finally, the acquired data is encapsulated by header to represent the data in MiniSEED format.

2.2. Decimation Filter

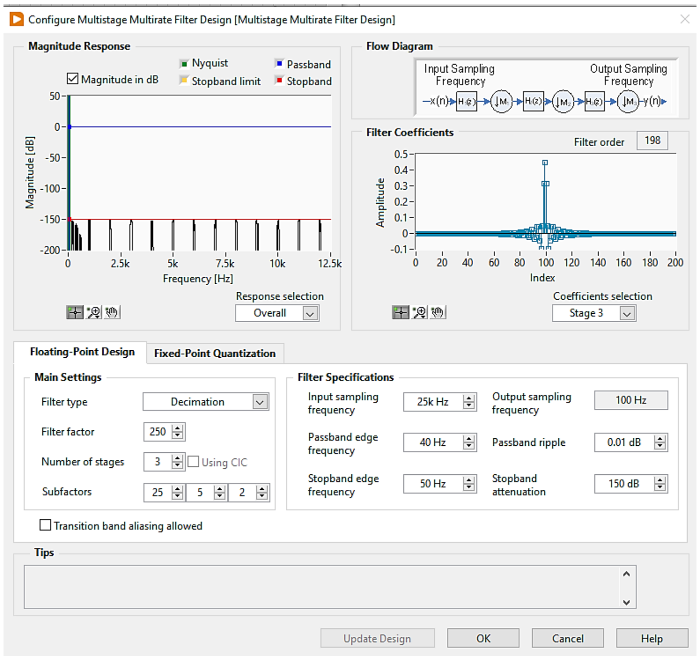
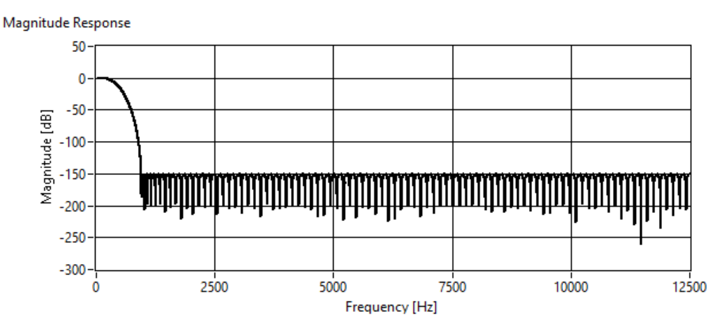
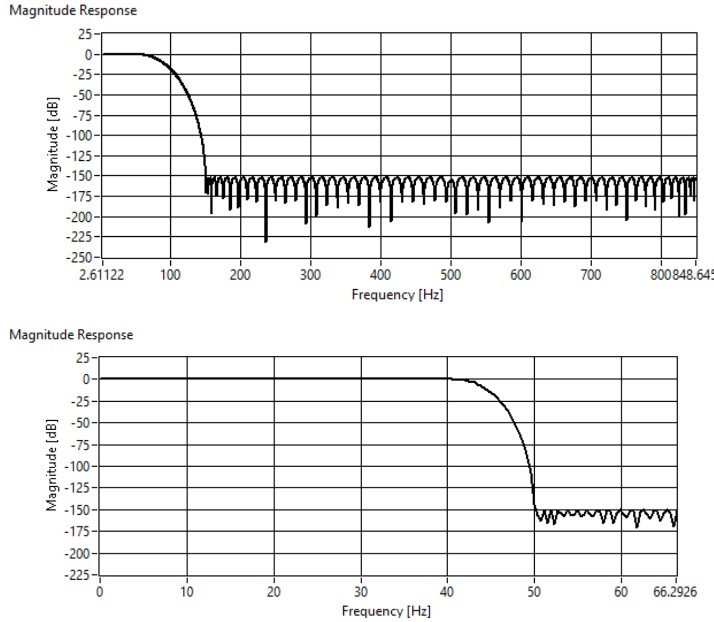


Figure 4 Multistage Multirate Filter Design

The digitizer is already designed to generate output sampling frequency according to user application. This can be done using multistage multirate filter design function as shown in Figure 4. The main settings of the filter design are the filter type, number of decimation stage, and decimation factors. Also, the user can configure the filter specifications including: the input sampling frequency, the passband and stopband frequencies, passband ripple, and stopband attenuation. So, our digitizer is scalable to generate wide range of different rates. We design three sequential filters to decimate the sampling rate to the desired one. The main settings of the filter are to decimate the input sampling rate from 25k Hz to 100 Hz using three stages. The factors of each stage are 25, 5, and 2. The passband edge frequency is 40Hz until reaching 50 Hz. The passband ripple is 0.01 dB, while the stopband attenuation is 150 dB. The resulting magnitude response for each stage is shown in Figure 5. Oversampling relaxes the requirements on an analog antialiasing filter.



(a)



(c)

Figure 5 The FIR magnitude response for (a) the first stage, (b) the second stage, and (c) the third stage.

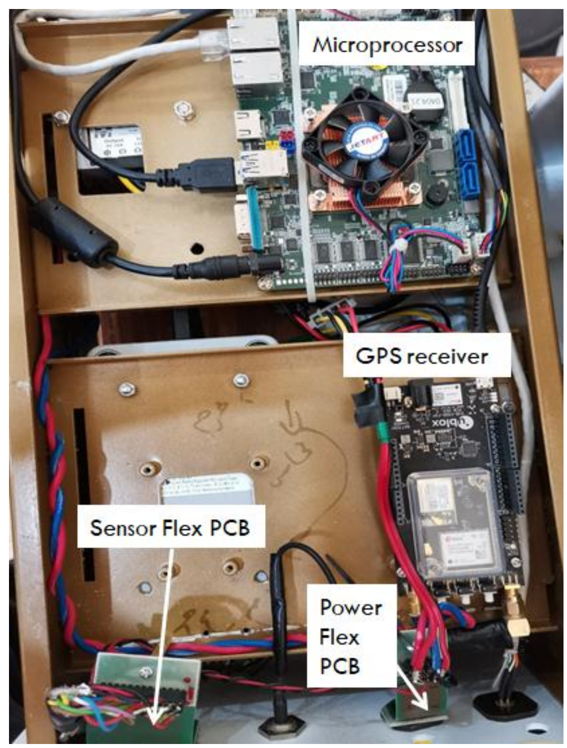


Figure 6 Upper layer of the system internal plate

2.3. System internal board

System internal boards is divided into two layers upper and lower. The upper layer is shown in Figure 6. Flexible PCB is designed for the sensor and power connectors. Unlike many rigid designs, a flex PCB is created out of materials that can bend, giving them improved resistance to vibrations and movement. Flexible PCBs are frequently built of polyimide or a comparable polymer which makes it to work for wide temperature range ranging from -200° C to 400° C. Thus, The Flexible PCB is suitable for harsher environments. All electronic boards are well fixed in a predefined location according to its dimension. The system internal plate is divided into upper and lower layers. The upper layer contains: Microprocessor, GPS receiver, and power converters. The main backbone in our system is the Microprocessor in which all programs and calculations are done. Also, it acquires the timing from the GPS receiver and archive seismic signal after being digitized from the A/D converter.

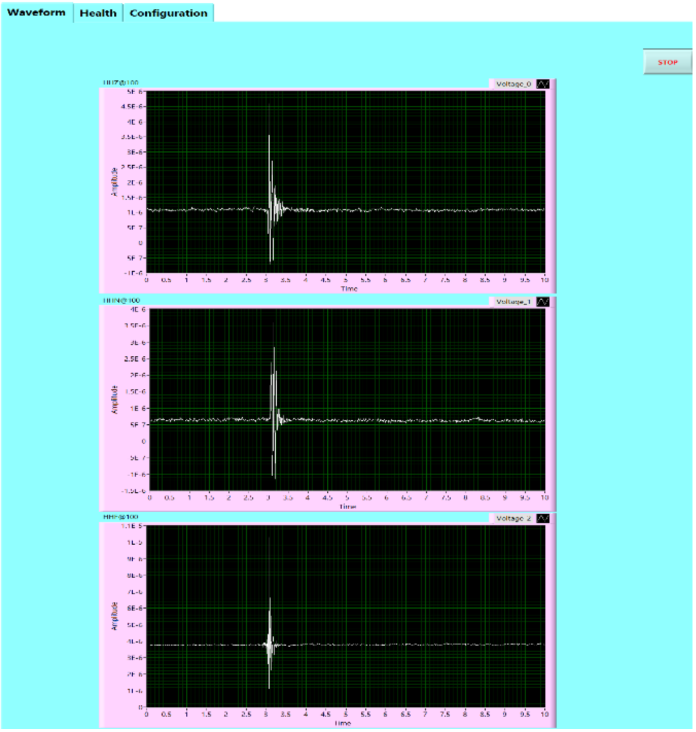


Figure 8 The recorded real-time seismic data using the implemented digitizer.

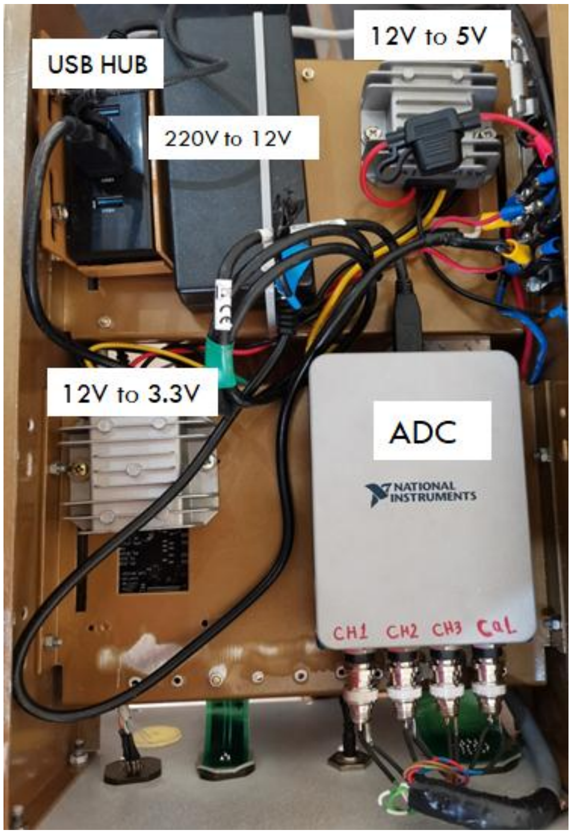


Figure 7 Lower layer of the system internal plate

Lower layer of the system internal plate is illustrated in Figure 7 10. The front-end circuit contains four channels: three channels for sensor reading and one channel for sensor calibration. Regarding to power requirements, there are three power adaptors for providing the system boards with 12V, 5V, and 3.3 V. Therefore, the prototype mainly is supplied by 12V DC either from solar battery in case of field installation or directly from the electricity adapter in case of testing.

2.4. Friendly User Interface

A friendly user interfaces for monitoring and controlling the proposed system had been built as shown in Figure 8. This interface is divided into three tabs. The Health tab indicates the GPS information and other information related to the data. We discriminate the output of the log file extracted from the GPS receiver in an organized view. The GPS information declares whether the GPS status is locked or unlocked, and the location information includes, the latitude and longitude coordinates and the time and date of the recording. Both the used sampling rate for the ADC and the output file path at which the data is stored, are included in the health tab. Finally, the configuration tab controls the setting parameters of the digitizer and the GPS receiver. The configuration tab consists of two menus: front-end ADC settings and communication port settings. The extracted waveform interval is controlled by adjusting the sampling rate and the acquired number of samples. The computer successfully receives data from GPS if the communication port is selected correctly and the baud rate is configured to 115200 bits/sec (as recommended in the GPS receiver manual).

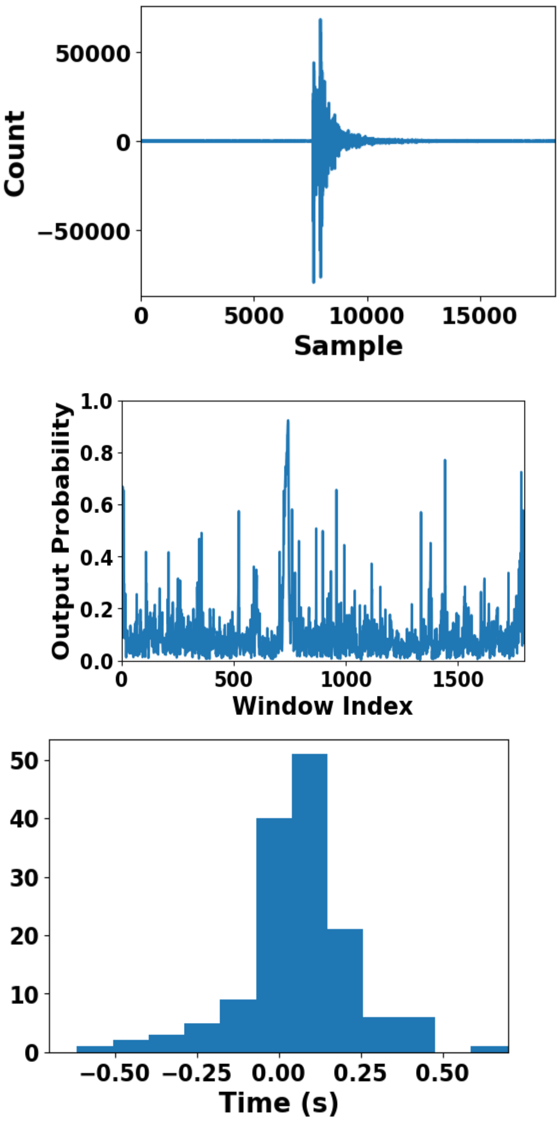
2.5. Picking Module

We add a picking module to the implemented digitizer to detect earthquakes. This facility allows the digitizer to release an alarm. Once an earthquake is detected which can support the earthquake early warning system (EEWS). Also, we can store the data related to the earthquakes based on the picked time by the picker which reduces the required storage size.

Here, we use a deep learning module to pick the first arrival time of the earthquake, i.e., CapsPhase [15]. Since the two pickers are implemented using Python, we add those modules as a Python block in the LABVIEW.

(a)

(b)



(c)

Figure 9 (a) Earthquake example. (b) The output probability of the CapsPhase. (c) The error distribution compared to the manual picks.

3. Results

Figures 6 and 7 show the front panel for the system and the internal design of the digitizer, respectively. The front panel consists of 4 main connectors sensor, GPS, power, and Ethernet. These connectors are military sockets. The sensor connector contains a 26-pin connector that should be connected to the seismometer via cable. This connector has the availability to take reading from the sensor in three directions: north-south (y-axis), east-west (x-axis), and vertical (z-axis). Then, the measuring signal is directed to the A/D converter. GPS connector connects the GPS receiver to the GPS antenna. The power socket is the main supply to the system with 12VDC from solar batteries. The Ethernet socket is to enable users to access the prototype locally using a web browser or remotely over a TCP/IP connection. Status LEDs function is to give user notifications about Over Power, Ethernet, and Timing. Two extra holes are drilled for any future use. From the tee Tob view, there is an upper cover for the prototype top part such as an LED screen display. The enclosure is designed to follow the IP68 rating. The user can manage and monitor ground motion records via an LED touch screen. The USB hub is connected directly to the microprocessor for data retrieval. Our system has two-way power sources: 1- solar battery, and 2- electricity. The power adapter socked can feed the system with power directly from electricity 220V and converted to 12V using a power adapter located internally in the system casing. All electronic boards inside the system need 12V to be powered on. Flexible PCB is designed for sensor and power connectors. All electronic boards are well fixed in a predefined location according to their dimension. The system's internal plate is divided into upper and lower layers. The upper layer contains Microprocessor, GPS receiver, and power converters. The main backbone of our system is the Microprocessor in which all programs and calculations are done. Also, it acquires the timing from the GPS receiver and archives the seismic signal after being digitized from the A/D converter. The A/D contains four channels: three channels for sensor reading and one channel for sensor calibration. Figure 8 shows the waveform of the real-time view of seismic waves based on the implemented digitizer.

On the other hand, we utilize the CapsPhase to detect the P-wave arrival time of the earthquake. To evaluate the performance of the CapsPhase, we use the Egyptian dataset used in [16-17]. The seismic dataset is recorded by the Egyptian National Seismic Network (ENSN) using three seismic stations. There are 153 waveforms corresponding to 53 earthquakes that happened in Egypt. The sampling rate is 100 Hz. Firstly, we filter the data between 1 Hz to 40 Hz. Since the CapsPhase is a window-based picker, i.e., each window has an output label, we divided each waveform into a group of windows, each window consisting of 4s (400 samples in case of 100 Hz sampling rate). Then, we apply the CapsPhase network to predict the P-wave arrival time. As a result, the CapsPhase detects 145 waveforms within 0.70s error compared to the manual picks. Thus, the CapsPhase has an accuracy of 94.77%. While the STA/LTA [18], the MODWT [16], and the spectro-ratio [17] has an accuracy of 76%, 83%, and 87%, respectively. We can conclude that the CapsPhase outperforms the benchmark methods. Figure 9(a) shows an example of an earthquake and the corresponding CapsPhase output probability (Figure 9(b)). We use 0.8 as an output threshold, where the sample index exceeds the pre-defined threshold is considered as the first arrival time of the event. Figure 9(c) shows the distribution of the error between the manual and the CapsPhase picks. As we can notice most of the error picks are around the zero which indicates the robust performance of the CapsPhase. For future work, we can use a transfer learning technique to further enhance the ability of the CapsPhase in picking the first arrival time accurately. We utilize the CapPhase module with the implemented digitizer as one of the main blocks in the LABVIEW project. Once the CapsPhase detects an earthquake, enable signal is released to take the appropriate action.

4. Conclusions

We design and implement a real-time digitizer to convert the analog seismic signal into a digital signal. Then, we store/transmit the digital signal to monitoring the seismic activity. The digitizer consists of several blocks. One of the main blocks is the decimation FIR filter, where the input seismic data is decimated to a low sampling rate, i.e., 100 Hz. The implemented digitizer is a trigger device, where a deep learning module is implemented to pick the first arrival time of the event. We use the CapsPhase network as a picker module, which shows robust picking accuracy compared to the benchmark methods. For future work, we will install the implemented digitizer in one of the seismic stations to evaluate the quality of the waveform by solving several earthquakes based on the stored earthquakes using our digitizer. Also, the CapsPhase network can be fine-tuned using more Egyptian seismic data for better results.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

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References

[1] K. Song, G. Cao, J. Yang, and P. Cao, “A high-precision synchronous sampling approach for large-scale distributed wire sensor networks in seismic data acquisition systems,” Instrumentation Science & Technology, vol. 40, no. 6, pp. 567–579, 2012.

[2] “Home | Nanometrics.” https://www.nanometrics.ca/ (accessed Aug. 14, 2022).

[3] “Kinemetrics.” https://kinemetrics.com/ (accessed Aug. 14, 2022).

[4] “REF TEK Systems Inc | Seismic Monitoring Systems.” https://reftek.com/ (accessed Aug. 14, 2022).

[5] “ION.” https://www.iongeo.com/ (accessed Aug. 14, 2022).

[6] “Sercel - Seismic acquisition systems.” https://www.sercel.com/Pages/default.aspx (accessed Aug. 14, 2022).

[7] X. Zhao, Q. Zhang, and M. Deng, “Super class‐AB bulk‐driven OTAs with improved slew rate,” Electronics Letters, vol. 51, no. 19, pp. 1488‐1489, 2015.

[8] G. Liang and W. Li, “Some thoughts and practice on performance improvement in distributed control system based on fieldbus and ethernet,” Measurement and Control, vol. 49, no. 3, pp. 109–118, 2016.

[9] A. M. Zambrano, I. Perez, C. Palau, and M. Esteve, “Technologies of internet of things applied to an earthquake early warning system,” Future Generation Computer Systems, vol. 75, pp. 206–215, 2017.

[10] O. M. Saad, A. G. Hafez, and M. S. Soliman, “Deep learning approach for earthquake parameters classification in earthquake early warning system,” IEEE Geoscience and Remote Sensing Letters, vol. 18, no. 7, pp. 1293–1297, 2020.

[11] Q. Zhang, M. Deng, J. Cui, and Q. Wang, “Research and development of one novel distributed digital seismic acquisition station,” Advances in Information Sciences and Service Sciences, vol. 4, no. 5, 2012.

[12] F. Guo et al., “Development of a new centralized data acquisition system for seismic exploration,” Geoscientific Instrumentation, Methods and Data Systems, vol. 9, no. 1, pp. 255–266, 2020.

[13] S. Qiao, Q. Zhang, and Q. Zhang, “Mine fracturing monitoring analysis based on high-precision distributed wireless microseismic acquisition station,” IEEE Access, vol. 7, pp. 147215–147223, 2019.

[14] M. Beyreuther, R. Barsch, L. Krischer, T. Megies, Y. Behr, and J. Wassermann, “ObsPy: A Python toolbox for seismology,” Seismological Research Letters, vol. 81, no. 3, pp. 530–533, 2010.

[15] O. M. Saad and Y. Chen, “Capsphase: Capsule neural network for seismic phase classification and picking,” IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1–11, 2021.

[16] A. G. Hafez, M. Rabie, and T. Kohda, “Seismic noise study for accurate P-wave arrival detection via MODWT,” Comput Geosci, vol. 54, pp. 148–159, 2013.

[17] A. G. Hafez, T. A. Khan, and T. Kohda, “Earthquake onset detection using spectro-ratio on multi-threshold time–frequency sub-band,” Digital Signal Processing, vol. 19, no. 1, pp. 118–126, 2009.

[18] A. Trnkoczy, “Understanding and parameter setting of STA/LTA trigger algorithm,” in New Manual of Seismological Observatory Practice (NMSOP), Deutsches GeoForschungsZentrum GFZ, 2009, pp. 1–20.