Automated detection of microearthquakes in continuous noisy records produced by local ocean bottom seismographs or coastal networks

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Received 8 June 2018; accepted 20 September 2018; published 1 March 2019.

Records of seismic waves produced by local ocean bottom seismographs (OBS) or coastal networks are noisy. The noises, such as high-amplitude microquakes, different anthropogenic noises related to engineering works, explosions, land and sea transport noises, microseisms, or the high-frequency ambient noise, complicate the detection of earthquakes and, in particular, microearthquakes in continuous records produced by local seismic networks. Here we present an algorithm for the automated detection of useful signals in seismic records contaminated by noises. Typical useful and noisy signals at offshore and coastal sites are described together with a brief analysis of the application of the well-known methods to detect useful signals. The proposed algorithm makes a use of the following observations: (i) an increase in the signal amplitude, (ii) consistency over different seismic stations, and (iii) the signal duration. The cumulative short-term-average and long-term-average envelope function is used to estimate the signal duration and to distinguish useful seismic signals from short high-amplitude noisy microquakes. The proposed algorithm was tested on the records produced by local network in the north Egypt coast zone during engineering seismological studies and revealed its effectiveness. *KEYWORDS:* Microearthquakes; OBS network; automated detection; ambient noise; microquakes; explosions.

Citation: Krylov, A. A., L. I. Lobkovsky, and A. I. Ivashchenko (2019), Automated detection of microearthquakes in continuous noisy records produced by local ocean bottom seismographs or coastal networks, *Russ. J. Earth. Sci., 19,* ES2001, doi:10.2205/2018ES000649.

1. Introduction

Nowadays, monitoring of seismicity in coastal and/or offshore zones is underway in many regions of the world, where hazardous installations such as nuclear power plants or offshore oil-and-gas production platforms are created.

Monitoring of seismicity is mostly realized using the local or regional networks of autonomous onshore and/or offshore seismic stations that often operate for long years. For keeping track of earthquake occurrences, a tried and tested system is required to quickly and efficiently process the huge data volumes containing accumulated seismic records. An effective solution of this task is to use at the most the algorithms and relevant software for automated detection and identification of useful microearthquake signals in continuous noisy seismic records with taking into consideration particular features of the noisy environment in coastal and offshore regions.

There are a variety of algorithms both for au-

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http://rjes.wdcb.ru/doi/2018ES000649-res.html

tomated detection of seismic events in continuous noisy records (phase detectors), and for more precise estimation of seismic phase arrival times (phase pickers). The brief overview of these algorithms having each their own advantages, pitfalls, and implementation area is presented below in chapter 2.

The goal of the present work is to search the most effective approach for automated detection of microearthquake signals in continuous noisy records produced at seismic stations of local monitoring networks operating in coastal and offshore zones. At achieving this purpose, the following investigations have been conducted: (a) characteristics of various noisy signals observed in coastal and offshore regions are considered, (b) analysis of application of the existing methods to solve the formulated task is presented, and, at last, (c) based on the known methods, a new algorithm has been developed, implemented, and tested which allows to effectively realize the automated detection of microearthquake signals in continuous noisy records produced at seismic stations operating in coastal and offshore regions.

2. Methods and Data

2.1. Characteristic Properties of Seismic Records Produced in Coastal and Offshore Regions

Seismic records produced at seismic stations operating at the sea floor or in coastal regions are complicated by the ambient seismic noise having some particular properties. Seismic noise observed at the sea floor is a subject of detailed studies presented in many publications [e.g., *Kovachev et al.,* 2000; *Levchenko,* 2005; *Ostrovsky,* 1998; *Soloviev,* 1985, 1986]. Seismic noise level at the sea floor is insignificantly lower than on land. By their origin, the observed seismic noises are divided into ambient seismic noise, instrumental noise (self-noise), and man-made (anthropogenic) noise.

When registration is made at the sea floor, similar to that on land, some weak high frequency seismic background noise is observed in the range 10–100 Hz and higher even after removing the influence of well-known sources of noise (Figure 1a). This background noise, often termed as regional noise, refers to the ambient seismic noise. The seismoacoustic emission, i.e. a growth of crustal defects under the impact of the long period seismic processes, appears to be the most probable generation mechanism of the regional noise.

Ocean microseisms are another kind of the ambient noise (Figure 1a). They are related to the low frequency spectral range, and a distinction is usually made between the smaller primary ocean microseisms (with a period 10–20 s) and more energetic secondary ocean microseisms (4–10 s) [*Ostrovsky,* 1998]. Primary ocean microseisms are generated only in shallow waters in coastal regions, whereas the secondary ocean microseisms are explained as being generated by the superposition of ocean waves of equal period travelling in opposite directions.

The specific kind of seismic noises observed at the sea floor are so-called microquakes – short (with a duration 0.3–3 s) high-amplitude spikes of uncertain origin (Figure 1b). Sometimes their amount can reach 90% of the total number of the recorded seismic events. Based on the results of experimental studies, the conclusion was made that microquakes can predominantly be related to the seafloor subsidence around the ocean bottom seismograph (OBS) installation site due to the relaxation of stress that existed in rocks before seismograph deployment, caused by the ground impact and weight of the instrument [*Ostrovsky,* 1998]. Similar signals can also be observed in the coastal zones of quite different regions. For example, the impulse signals similar to those presented in Figure 1b have been also recorded at the coast of Mediterranean Sea in northern Egypt and at the coast of Laptev Sea in northern Russia. Study of the nature and mechanism of such a noisy signals is a scope of separate investigation.

During the seismological observations on land, seismographs are typically installed on outcropped hard or firm rocks, while an ocean bottom seismographs can often be installed on the loose marine deposits, and, hence, in case of some particular properties of soils, a manifestation of specific noise and distortion of seismic signals is highly likely. High-frequency components of seismic signals decay very rapidly with distance in such deposits. In addition, some resonance effects occur in the system “bottom-instrument”, so that such distortions of the seismic waveforms are termed coupling-effect

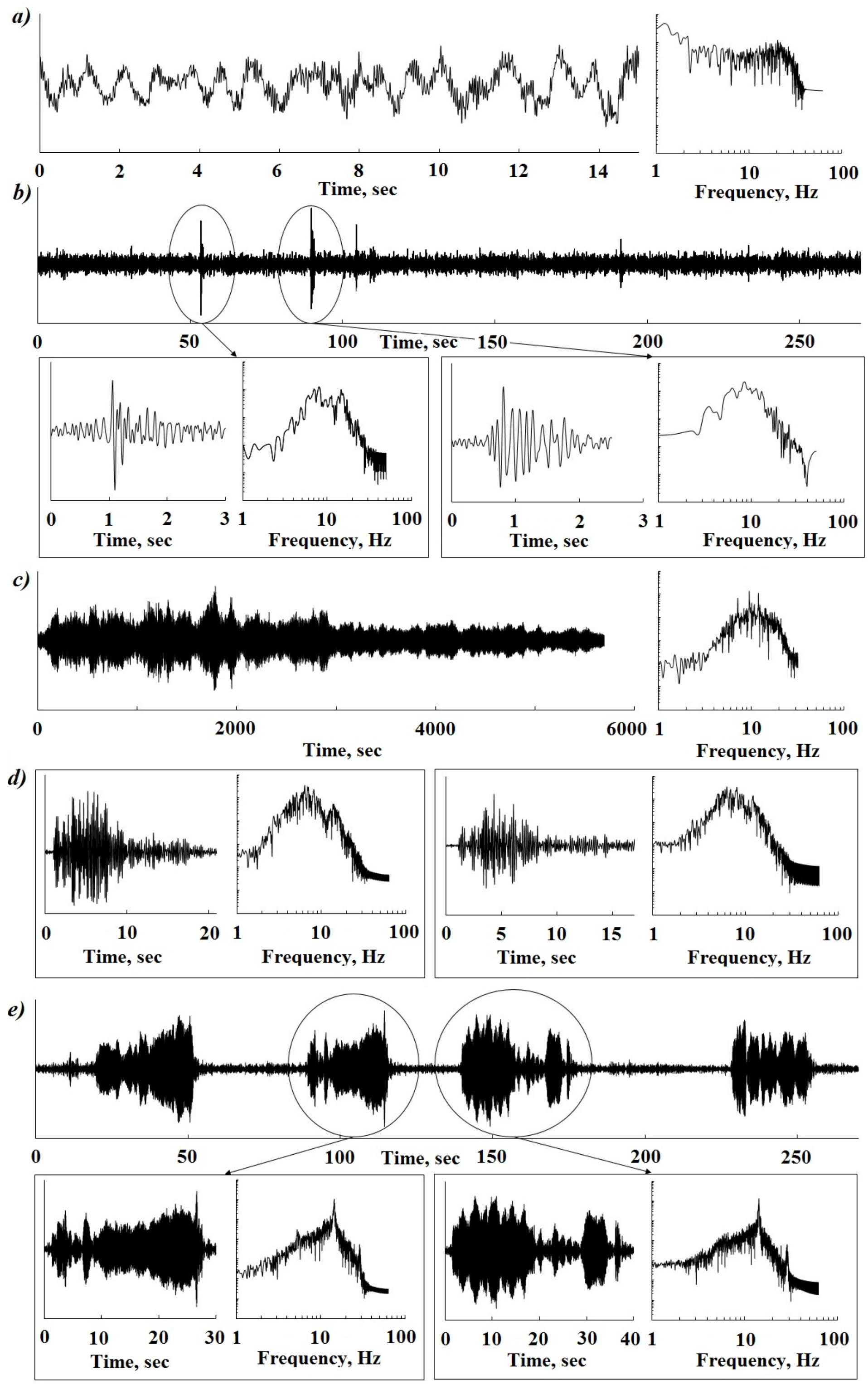

Figure 1. Various non-earthquake noisy signals recorded in coastal and offshore regions and their Fourier amplitude spectra: a) microseisms and high-frequency ambient noise (shelf of the Baltic Sea, OBS record); b) high-amplitude microquakes (shelf of the North Caspian Sea, OBS record); c) ship traffic noise (shelf of the Black Sea, OBS record); d) explosions (coastal zone of the North Egypt, onshore record); e) noisy signals produced by engineering works (coastal zone of the North Egypt, onshore record). See text for details.

[*Levchenko,* 2005; *Ostrovsky,* 1998]. Seismological observations at the sea floor show that a certain type of seismic noise can be also generated by the near-bottom currents. The spectrum of such noisy signals can overlap the frequency range of the modern broadband seismographs [*Levchenko,* 2005].

Different man-made (anthropogenic) noises (Figure 1c–e) mainly include: (i) noise produced by industrial and transport operations, (ii) ship traffic noise, (iii) industrial or specifically prepared explosions, and (iv) signals produced by onshore and offshore geophysical surveys.

Instrumental noise (self-noise) and signal distortions depend on the type of sensors and recorders used in the sea-floor observations [*Ostrovsky,* 1998].

It is worthy to note a specific type of signals observed in both offshore and coastal registration and do not relate them to marine noises – T-phase, which represents a hydroacoustic wave train generated by underwater earthquakes and propagating at great distances. Observed frequencies of T-phase occupy the range from 2 to 150 Hz and depend on the intensity, depth and properties of the seismic source, medium Q-factor, and other parameters. The record of T-phase has a spindly form due to the wave interference [*Soloviev,* 1986].

2.2. Analysis of Application of Existing Methods for Automated Detection of Microearthquakes in Noisy Records Produced in Coastal and Offshore Regions

During monitoring of seismic activity, detection and identification of local and regional earthquakes as well as microearthquakes is performed. In addition, in regions of low seismic activity, it is also required to detect and identify the industrial or special explosions and signals produced by different geophysical surveys and engineering works which are further used to estimate the relative intensity of ground motions. Therefore, by no means all of noisy signals are necessary to be ignored. Usually microseisms are investigated separately, and here their processing is skipped. It is worthy to note that processing of seismic records should be operative and simultaneous for the entire network, which constrains the complexity and computational capacity of selected algorithms. Besides, analysts often have no prompt access to high performance computer clusters.

Most of the described in literature detection methods have been developed for records produced by permanent stations of the global earthquake monitoring networks rather than for local networks, and moreover with taking into consideration particular features of their deployment region. Hence, their application in unmodified state to the records produced by local networks in coastal and offshore regions becomes ineffective for automated detection of microearthquake signals.

For example, let's consider the most wide spread "energetic" detection algorithm STA/LTA [*Allen,* 1978, 1982], in which the ratio of average values of some characteristic function (CF) in moving short (STA) and long (LTA) windows is calculated, and the time moment of rapid increase in CF amplitude with regard to preceding time interval is determined. By varying the length of STA and LTA windows as well as the threshold value of detection one can change the sensitivity of the algorithm and establish the type of seismic event making the algorithm to trigger into detection. The smaller the length of STA window, the more sensitive is the algorithm to the weak local events having a short signal, and vice versa. The length of LTA window, in turn, influences the sensitivity of algorithm to the regional seismic events with relatively gradual P-wave onset [*Trnkoczy,* 2012]. At present time, there are a variety of modifications of STA/LTA algorithm which are widely applied [*Baer and Kradolfer,* 1987; *Diehl et al.,* 2009; *Earle and Shearer,* 1994; *Ruud et al.,* 1993; *Vassallo et al.,* 2012].

As mentioned above, the seismic records produced in coastal and offshore regions contain a large number of high-amplitude noisy microquakes and different anthropogenic signals, such as explosions, transport and geophysical survey noises (Figure 2). Spectra of these signals overlap spectra of earthquakes (Figure 1), and hence it is impossible to reject them using the bandpass filters. Noisy microquakes have a rather short duration (0.3–3 s), which distinguish them, for example, from signals of regional earthquakes of much longer duration. Setting the STA/LTA parameters in order to ignore such microquakes leads to missing of weak local seismic events. On the other hand, long-continued noisy signals with gradual amplitude rise produced by transport and signals generated by geophysical surveys complicate the detection of regional seismic events using the STA/LTA algorithm (Figure 3).

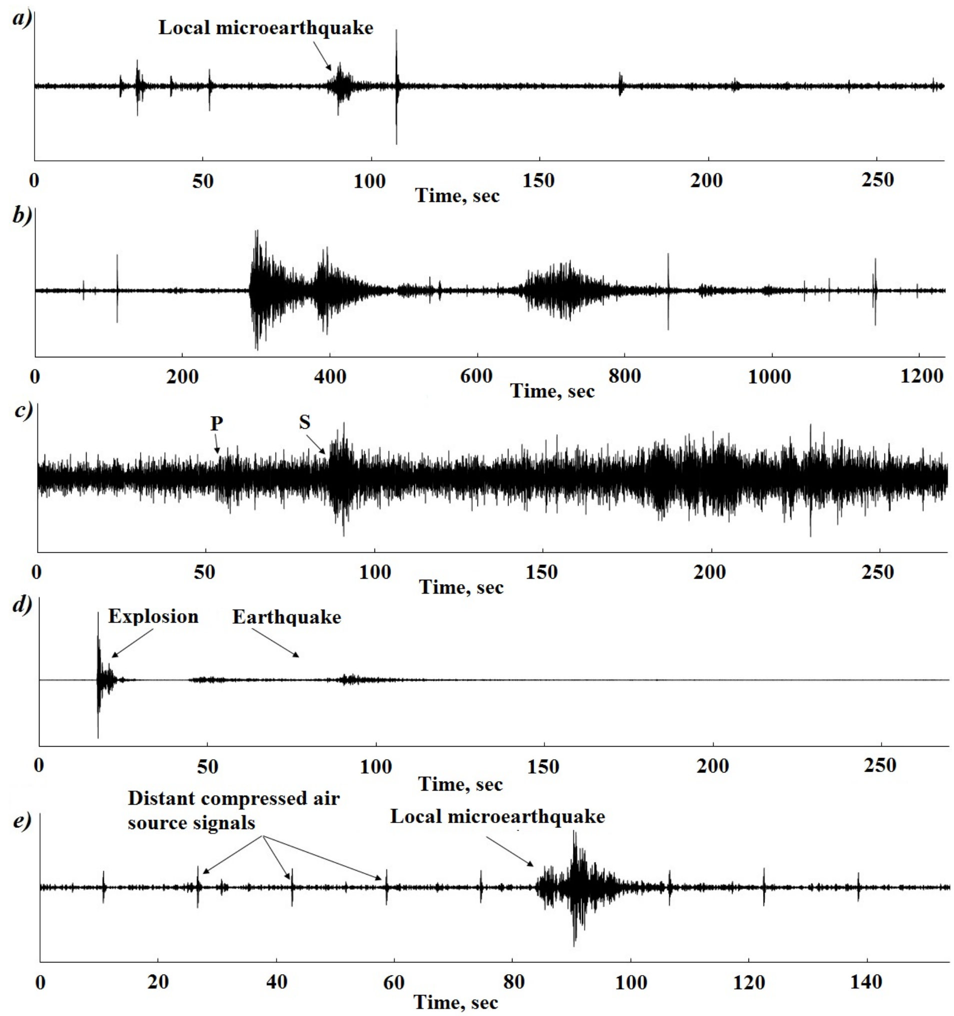

Figure 2. Seismic records containing earthquake signals and various non-earthquake noisy events complicating the automated detection of earthquake signals: a) local microearthquake and high-amplitude noisy microquakes (shelf of the Black Sea, OBS record); b) regional earthquake and high-amplitude noisy microquakes (shelf of the Black Sea, OBS record); c) local microearthquake buried in the ambient noise (coastal zone of the North Egypt, onshore record); d) regional earthquake preceded by the explosion (coastal zone of the North Egypt, onshore record); e) local microearthquake and distant compressed air-gun signals (shelf of the Black Sea, OBS record).

Various modifications of the STA/LTA algorithm allow to improve the quality of detection to some degree [*Diehl et al.,* 2009; *Earle and Shearer,* 1994; *Vassallo et al.,* 2012]. For example, consideration of the signal frequency contents using a set of bandpass filters or wavelet transforms might help to avoid missing of seismic event due to a low-frequency noisy signal [*Baranov,* 2007]. It should be noted that STA/LTA algorithms estimate the phase arrival time imprecisely and hence might be only applied to detect useful signals as many authors have indicated [*Asming,* 2017].

Another approach of automatic detection is the use of autoregressive schemes (AR) in which the values of a time series at some time moment depend linearly on the preceding values of the same time series [*Leonard,* 2000; *Leonard and Kennett,* 1999; *Sleeman and van Eck,* 1999; *Takanami and Kitagawa,* 1988]. For example, the autoregressive algorithm AR-AIC-picker is used for precise phase

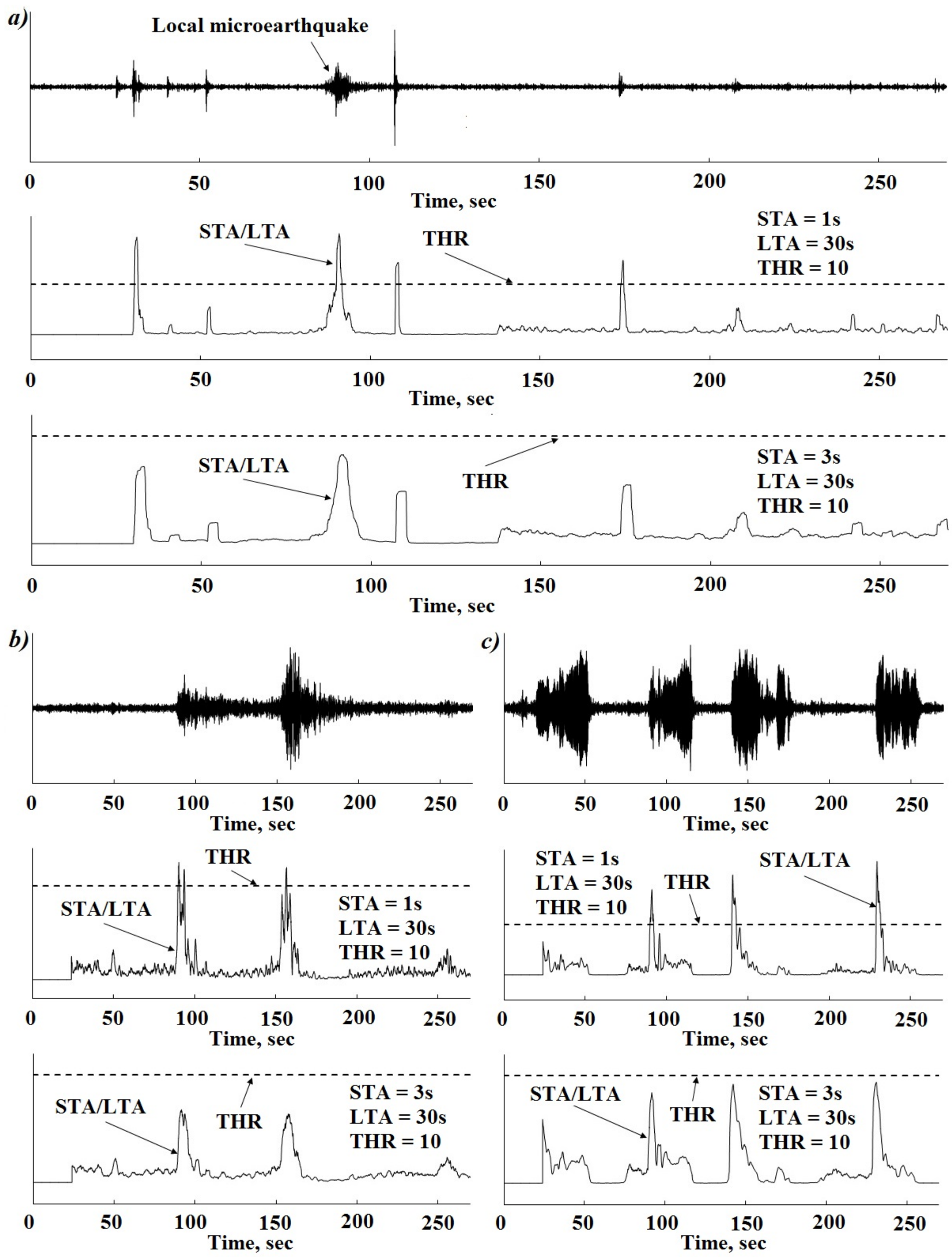

Figure 3. Examples of the STA/LTA algorithm performance with different parameter values for different seismic events: a) local microearthquake and a series of noisy microquakes; b) regional earthquake with clearly seen P and S phases; c) noisy signals produced by engineering works. Three plots for each example show: upper – raw record; middle – events are detected by the algorithm; lower – events are missed by the algorithm.

detection [*Leonard,* 2000]. However it is also based on the determination of the time moment when a sharp change in signal amplitude occurs and is computationally quite expensive. Autoregressive schemes as well as the methods based on the polarization analysis [*Ross and Ben-Zion,* 2014] are more appropriate for precise phase identification in the already detected sections of the record.

To solve the problem of automated detection, classification and identification of different phases in seismic records, many other approaches have been involved, such as artificial neural networks

[*Madureira and Ruano,* 2009; *Romeo,* 1994; *Zhao and Takano,* 1999], wavelet denoising [*Al-Hashmi et al.,* 2013; *Anant and Dowla,* 1997; *Liu et al.,* 2000; *Rastin et al.,* 2014], fractal analysis [*Bochetti et al.,* 1996; *Liao et al.,* 2010], polarization analysis [*Cichowicz,* 1993; *Jurkevics,* 1988; *Park et al.,* 2004; *Ross and Ben-Zion,* 2014; *Vidale,* 1986], fuzzy logic based expert systems [*Gvishiani et al.,* 2008; *Maurer and Dowla,* 1994].

Correlation techniques of automated detection of seismic events in records are spread to a lesser extent, because they imply the use of a suite of pattern records of seismic events. These methods give good results in recognition of useful signals under the following principal conditions: (a) being used in processing of the data of permanent long-term observations in a single region; and (b) given a vast database containing both useful and noisy signals which are characteristics of the studied region. Furthermore, the seismic monitoring is performed in quite different regions, which put the constraint on algorithmic universality with regard to various noisy environments. The same comment refers to the methods based on the use of neural network approach [*Zhao and Takano,* 1999].

2.3. Development of a New Approach to the Automated Detection of Useful Signals in Noisy Seismic Records Produced in Coastal and Offshore Regions

The processing of continuous records produced at the stations of local monitoring system includes the following main steps (the analysis of noises and microseisms is not discussed in the present work):

- Detection of earthquakes, microearthquakes, and explosions;
- Precise phase identification of seismic events in the detected record sections;
- Determination of the main earthquake parameters: hypocenter coordinates and magnitude.

In present work the first step is only considered. The principal requirements applicable to the developed algorithm are as follows:

- Detection of useful seismic signals of the local and regional earthquakes, microearthquakes and explosions; forming the event bulletin and a suite of the record sections containing the detected events;
- Minimization of false triggering of the algorithm in case of noisy signals characteristic of the coastal and offshore regions, such as noisy microquakes, transport activities, geophysical surveys, etc.;
- Providing the computational cost of the algorithm appropriate for performing operative processing of records including in-field processing.

Based on the past experience in manual processing of the records produced by sea bottom and coastal seismographs, the following approach of solving the formulated task is proposed.

First, it appears appropriate to divide the tasks of seismic event detection from the precise phase identification to provide analysts the opportunity to control the intermediate results. With regard to the microearthquake detection in noisy seismic records, the existing algorithms have a poor precision, and therefore, the overall automation of integrated event detection and phase identification of weak and short microearthquake signals will cause a large number of errors.

Secondly, based on the analysis of existing algorithms of event detection and phase identification and taking into consideration the above mentioned particular properties of noises recorded in coastal and offshore regions, it has been proposed to use jointly the following criteria for automated signal detection: (a) increase in signal amplitude, (b) consistency of events detected in records of different stations, and (c) signal duration.

The main blocks of the proposed algorithm are presented in Figure 4. At the first stage, the records produced by seismographs are processed using digital bandpass filters in order to improve the signal-to-noise ratio (SNR):

$$x_f(t) = x(t) * h(t, \Delta f)$$

where $x(t)$ is a raw seismic record; $x_f(t)$ – the filtered record; and $h(t, \Delta f)$ – impulse response of the bandpass filter. This stage is very important for the detection of weak local events; for example, applying the filter with a bandpass of 6–16 Hz allows detecting a weak useful signal which otherwise is completely masked by the stationary noise (Figure 5).

At the second stage, the algorithm STA/LTA is applied separately to the filtered seismic records of all network stations. The classical formula is used

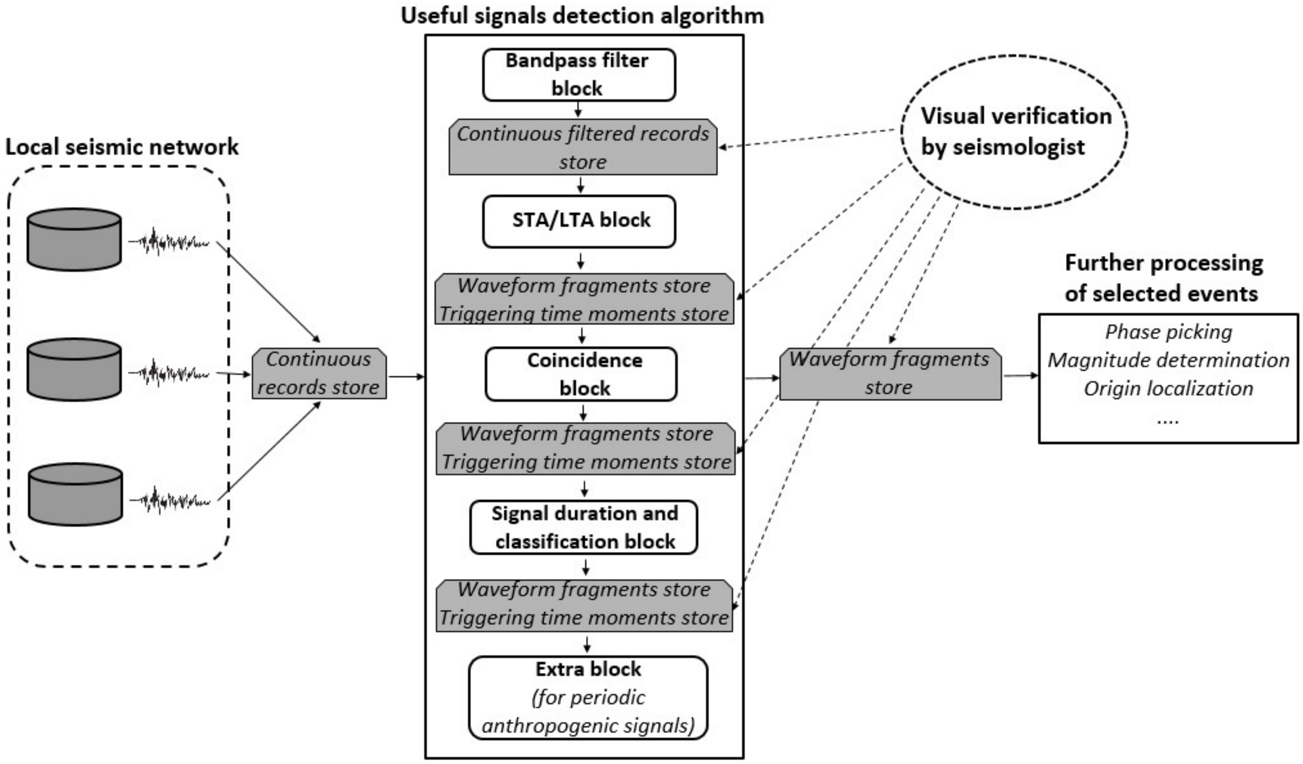

Figure 4. Control flow-charts of the proposed algorithm for automated detection and identification of microearthquake signals in continuous noisy records produced at the stations of local monitoring system operating in coastal and offshore regions.

to calculate the STA/LTA ratio:

$$r_i = \frac{\mathrm{STA}}{\mathrm{LTA}} = \frac{\frac{1}{ns}\Sigma_{j=i-ns}^{i} x_j^2}{\frac{1}{nl}\Sigma_{j=i-nl}^{i} x_j^2}$$

The length of STA and LTA windows as well as the threshold value for triggering detection are adjusted in such a way that even relatively small and short spikes in signal amplitude cause algorithm to trigger detection. In this way the detection of weak local events is achieved.

At the third stage, consistency of the events detected by STA/LTA block in records of different stations is checked. Block of the consistency check allows eliminating some part of noisy microquakes, transport signals and other anthropogenic noises. A consistency logic criterion K is introduced for consistency checking, so that the detected by the STA/LTA block events with time moments $T_1, ..., T_n$ within some interval are considered as being consistent. It allows taking into account both the difference in travel time of seismic waves from the source to different seismic stations and the possibility of STA/LTA block triggering at different phase arrivals of the same event:

$$K = (T_1 \in \mathrm{LAG})\ \&\ (T_2 \in \mathrm{LAG}) \& \ldots$$

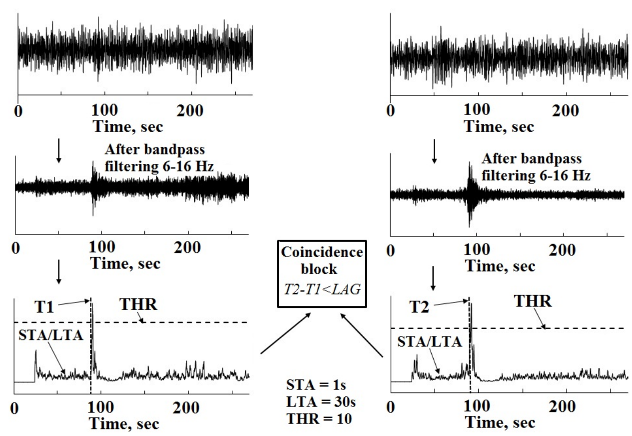

Figure 5. Example of the proposed algorithm performance for the same event recorded at two different seismic stations: left – station 1; right – station 2. Three plots for each station show: upper – raw record; middle – record after bandpass filtering (6–16 Hz); lower – detected events at both stations are compared with each other for consistency.

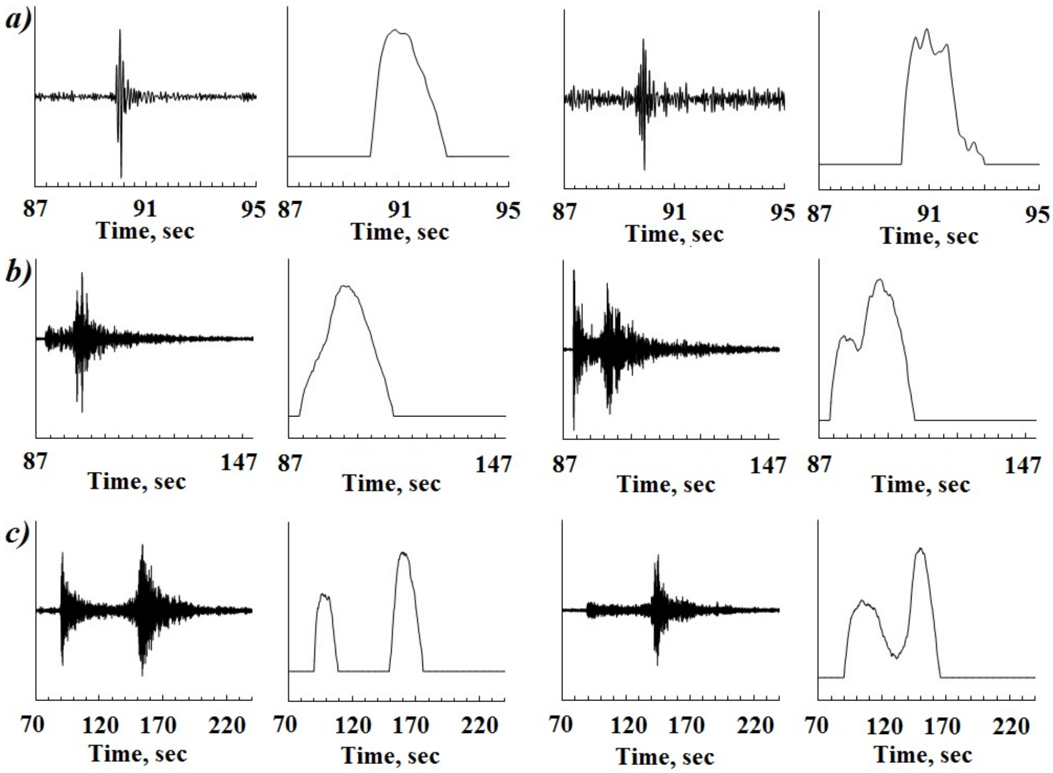

Figure 6. Examples of the signal duration block performance for different detected seismic events: a) high-amplitude noisy microquakes; b) local microearthquakes, c) regional earthquakes. Automated estimates of the duration for each detected seismic event are shown to the right of the event records.

$$\&(T_n \in \mathrm{LAG})$$

In addition, block of the consistency check allows reliable detecting of those events that are clearly seen in records of several stations at once, which is very important for reliable localization of the detected event.

Block STA/LTA and the consistency check block do not help to avoid a large number of false detections. A presence of a vast amount of impulse noises produces an incident correlation of noisy microquakes at different seismic stations within the accepted time interval LAG. Signals produced by different geophysical surveys and engineering works can also be recorded at several seismic stations at once, hence a further signal classification is required at the output of the consistency check block, which can be performed both: visually by analyst and automatically.

It is proposed to use the signal duration as the simplest criterion for such classification in automated signal detection. Analysis of signal duration appears to be an effective tool for separation of useful signals from noisy microquakes. Definition of the signal duration can be made in different ways; at present work the following expression is used [*Baranov,* 2007]:

$$C_{i+1} = C_i + \ln \frac{\mathrm{STA}_i}{\mathrm{LTA}_i} \tag{1}$$

Some estimates of the duration of various useful and noisy signals obtained using the equation (1) are presented in Figure 6. Signal duration estimates are also useful for further automated determination of magnitude of the local seismic events (coda wave magnitude).

Periodicity of block STA/LTA triggering at one or several seismic stations can serve as an additional criterion of classification for separation of ambient noises from noises produced by engineering works (Figure 1e).

It is worthy to note that any algorithm of automated signal detection against the background noise is non-perfect and leads to both the missing

Table 1. Input Parameters Used for Testing of the Proposed Algorithm

Δf, Hz	6–16	LAG, s	60
STA, s	1	PER	4
LTA, s	30	STAenv, s	0.2
Threshold value	10	LTAenv, s	30
CoincIndex	2	SpikesLen, s	5

Note: Δf – frequency band of the digital filter; STA – length of the moving short-term window in STA/LTA block; LTA – length of the moving long-term window in STA/LTA block; Threshold value – triggering threshold for STA/LTA ratio; CoincIndex – minimum number of stations for making positive consistency decision; LAG – accepted time span for the block of consistency check; PER – minimum number of trigger alarms with almost equal intervals in order to classify the signal as produced by engineering works; STAenv – length of moving short-term window in signal duration block; LTAenv – length of moving long-term window in signal duration block; SpikesLen – maximum duration of the envelope ($C > 0$) to be assigned to the microquakes.

of useful signals (errors of the first kind) and the false detections (errors of the second kind). It is useful to remain the opportunity for visual control of results at the output of each block of the algorithm and for saving corresponding suits of records containing both useful and noisy signals for further analysis of the algorithm performance (Figure 4).

3. Study Results and Discussion

The block structure of both the computer program and the presentation of results allows conducting a stage-by-stage control and analysis of correctness of the proposed algorithm performance. The STA/LTA calculations are carried out by means of the parallel computing which provides a significant performance gain of the program even when using a single multi-core laptop. Such increase in productivity rate is especially desirable for in-field processing of available seismic recordings. After executing the STA/LTA block, the algorithm only works with the detected fragments of the record without repeated search of required sections in the record, which also increases the algorithm performance.

For testing the proposed algorithm, the continuous seismic records produced by seismic monitoring system which have been established with participation of the Institute of Oceanology of the Russian Academy of Sciences at the Mediterranean coast of northern Egypt since 2016. The local monitoring network consists of eight short-period three-component seismographs Lennartz LE-3Dlite Mk II (with natural frequency 1 Hz, and sample rate 125 Hz). The choice of these records for the algorithm testing is due to the best quality of waveform recordings, used equipment, and time synchronization as compared with the other available raw data.

Input parameters used for testing of the algorithm are presented in Table 1. The total duration of test records is equal to one month (November 2017).

The automated processing of the chosen test recordings using the proposed algorithm resulted in the following outputs: (a) 6126 candidate sections of the continuous one-month record were detected at the output of STA/LTA block; (b) 989 events were identified at the output of the next, consistency check block; and (c) 71 signals of local microearthquakes or explosions (with epicentral distance less than 300 km), and 138 signals of regional earthquakes (with distance more than 300 km) were finally recognized at the output of the last, classification block.

In general, performance statistics of the proposed algorithm of automated signal detection against the background noise could be considered as satisfactory bearing in mind some particular issues associated with further processing of the detected record sections as well as with the above mentioned characteristic features of the studied regions.

First, the further processing consists in precise localization of detected seismic events in space. In our case the use of widely spread localization methods based on the inversion of seismic wave travel times is preferable because of their higher precision as compared to the other methods. For this reason consistency of the detected signals at different seismic stations of local network was chosen as one of their detection and identification criteria. Omission of a seismic event occurred mainly due to either its registration at only one station or if the SNR ratio was not sufficiently great for reliable estimation of seismic phase arrival times. This remark predominantly refers to recordings of regional earthquakes occurred at a large distance from the network (more than 300 km), and usually such events are of a little interest for a local seismic monitoring.

Secondly, in further processing of the detected and identified seismic events it is necessary to determine their magnitude or energetic class. However, determination of magnitude of microearthquakes using their recordings produced by bottom and coastal seismographs as well as conventional methods, i.e. by the ratio $A_{\max}/T$, where $A_{\max}$ – amplitude of the maximum phase, and T – oscillation period, raises difficulties because of the absence of calibration tables describing decay of seismic wave amplitudes with distance. For such cases, [*Bisztricsany,* 1958] proposed a new method for the determination of the magnitude of earthquakes based on measuring the duration of a seismic event record which was widely spread in the international seismological practice.

In subsequent years, the following relationship becomes widespread in practice of the local magnitude determination based on the duration of a seismic event on records produced by ocean bottom seismographs:

$$M_l = 3.24 \log \tau - 3.84 \qquad (2)$$

where τ is the earthquake coda duration on record (sec), i.e. the time interval between the time moment of the first arrival of P-wave and the time moment when coda amplitude becomes nothing more than 1.5 times the amplitude of background seismic noise. This relationship was inferred as a result of a series of experiments with ocean bottom seismographs in the area around the Crete Island in Aegean Sea [*Kovachev et al.,* 1991]. Coefficients of the inferred relationship (2) proved to be very close to those inferred by other researchers in different regions of the World Ocean [*Soloviev and Kovachev,* 1994].

For this reason, incorporation of the duration of recorded seismic event into the proposed detection algorithm as a classification criterion allows in the short term performing automated determination of the magnitude of seismic events. However, such an automated magnitude determination needs a more rigorous validation and detailed precision estimation.

4. Conclusion

Addressed in the present work problem of effective processing of continuous noisy records produced by detailed seismological observations in the coastal and offshore regions is closely related to the general delay of advanced studies in the field of marine seismology which is manifested in a vast unexplored areas and in absence of consistent methodology.

A description of useful and noisy seismic signals that are characteristic of the coastal and offshore regions is presented. A brief analysis of applicability of existing methods of automated signal detection against the background noise is carried out. A new algorithm of automated detection of microearthquakes and regional earthquakes which accounts for particular features of seismic records produced in the coastal and offshore regions is proposed.

A good statistic of detection and classification procedures, simplicity and high performance rate may be referred to advantages of the proposed algorithm. Pitfalls of the new algorithm are: (a) missing of weak signals of remote regional earthquakes, recorded only at one station; (b) often false consistency of earthquake signals with noisy signals produced by different engineering works in the area under monitoring; and (c) insufficient informational contents of the signal duration as a classification criterion.

It should be noted that indicated pitfalls are not crucial at achieving goals of seismic monitoring for engineering needs, and proposed algorithm can be effectively applied in practice.

However, the algorithm should only be applied for automated detection of useful seismic signals against the background noise in continuous noisy records. Tasks of automated estimation of seismic phase arrivals, hypocenter localization and magnitude determination using records of detected events is a subject of further development of tools for automated processing of recordings produced at stations of local monitoring systems operating in coastal and offshore regions.

Acknowledgments. The present work was conducted for the Russian state assignment (pr. No 0149-2019-0005) and partially supported by the Russian President Grant for young scientists (pr. No 0149 No MK-5963.2018.5; a review and analysis of applicability of existing methods, the concept of the proposed algorithm), the Russian Science Foundation (pr. No 14-50-00095; the implementation and application of the proposed algorithm), the Russian Foundation for Basic Research (projects No 18-35-00474 mol_a and 18-05-01018 A) and the State program (5–100 project) for increasing the rankings of the leading universities of the Russian Federation in the top-100 world universities ranking (description and illustration of different earthquake, explosion and noise signals). The author would like to thank S. A. Kovachev for helpful advices and providing the raw data of local OBS and coastal networks deployed by the seismology team of the Shirshov Institute of Oceanology of the Russian Academy of Sciences in several regions at different time.

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