Developing a block diagram for the earthquake warning device.

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Additional determination of the earthquake characteristics from the data of each separate station is perspective way in developing the earthquakes early warning systems. It allows using advantages of a method of the single sensor and, first of all, to reduce a radius of a dead zone, in which the warning is impossible, up to 20 kilometers and even less. However if the separate stations are used as a part of a seismic network, the end user loses such useful properties of his station, as possibility of independent activity and simple way to transfer a warning signals. This work is devoted elimination of these contradictions.

There are two methods to implement ultrashort warning of an earthquake that has occurred: the method based on a dense network of seismic stations and the "single sensor" method. Both of these have their own advantages and drawbacks [*Wu, Kanamori*, 2005].

The advantages of an early warning system based on a seismic network include a high reliability of warnings and the prediction of earthquake shaking intensity at each site in the alarm area.

The main drawbacks of such systems:

- complexity and high costs related due to the deployment of a dense network of seismic stations;
- unreliable operation during later shocks in case some of the stations, power supply or communications facilities have been damaged;
- the presence of an extensive dead zone (~50 km) where no warning is possible;
- difficulties in providing relevant information to the user;
- the necessity of deploying the sensors at low-noise sites.

The advantages of the early warning systems based on the "single sensor":

- expensive seismic networks are not required;
- self-contained operation is possible;
- the dead zone is reduced to 20 km or still less;
- information comes directly to the end user.

However, these systems also have significant drawbacks: the warnings are less reliable compared with the network-based systems and earthquake shaking intensity is not calculated.

In this connection it seems promising to develop a hybrid warning system, the "single sensors" being incorporated in the final ultrashort warning system [*Kanamori*, 2005].

The basic principles underlying the operation of this system have been formulated. In order to implement an earthquake warning system based on the principle of a "single sensor", we must have the following prerequisites [*Gravirov et al.*, 2010]:

- ✓ The identification of first earthquake onsets in a noise whose amplitude exceeds that of the signal. The assumption is that the noise involves diverse types, viz., stationary and nonstationary, chaotic and impulsive.
- ✓ The determination of basic earthquake characteristics from identified signals (approximate magnitude and epicentral distance).
- ✓ The use of fast algorithms and convenient hardware implementation.
- ✓ High adaptability.
- ✓ The system should be able to operate after the main earthquake has arrived.
- ✓ Service and deployment simplicity, low cost.
- ✓ The option of self-contained operation.
- ✓ Information connectivity to external systems.
- ✓ The requirements on operative parameters (temperature, humidity, power supply, magnetic fields, and vibration).

The most simple system realization is shown in Fig. 1.

Below we briefly describe each of the units presented in the diagram.

The power supply unit is connected to the mains. The unit must provide a stable power supply for all the other permanent and temporarily connectable units. When there is an interruption in the mains supply, the unit must provide for self-contained operation during at least 14 days.

The sensor is a three component accelerometer with a linear response function in the range between 0.1 and 10 Hz. The sensor is rigidly clamped in order to prevent the device from being displaced and torn off from the base during strong ground motion. The sensor mechanics and electronics must survive the shaking of a major earthquake. The protection against temperature changes must ensure that the time constant τ_t be equal to at least three hours. A cassette implementation of the device is possible involving foam sealing.

The ADC. Two ADC types can be used for transforming seismic signals whose spectrum is concentrated in low and very low frequencies (from the standpoint of electronics), but which have a wide dynamic range, namely, those based on multiple integration or on the sigma delta conversion. Such ADCs have the greatest number of digits (resolution), which ensures signal conversion without distortion in a dynamic range as great as 140 dB (with 24 bits).

Comparison between these two ADC types shows that, with about the same accuracy of conversion, the microchips of the sigma delta converter are much cheaper, and this makes them preferable. The sampling rate is 100 Hz.

The communications unit allows data from the "single sensor" system to be input into the existing network systems, a local network to be organized consisting of "single sensors", and the alert signal to be transmitted to a remote user. Apart from being sent from the **alert signal generation unit** to the seismic network data center, the warning signal can also be sent from the data **processing unit**, provided the amplitude exceeds a definite level (10^3 mm/s, say).

The adjustment-testing unit allows the sensor to be calibrated, the system operation to be tested, and permits specifying the system's sensitivity and initial probability levels at which earthquakes are to be detected. The unit enables visualization of seismic signals.

The alert signal generation unit generates electrical earthquake alert signals at five levels depending on the probability of the event in question. At lower probability levels alerts may be declared in a fire station, blocking may be enabled for the doors of buildings at open position, data saving in computer centers, and so on; at higher levels one would require shutdown of hazardous facilities and a public alert signal. Also the generation of a call-off alert signal is envisaged. The generation unit can receive connections from sonic and light warning devices that are powered by the system's power supply unit.

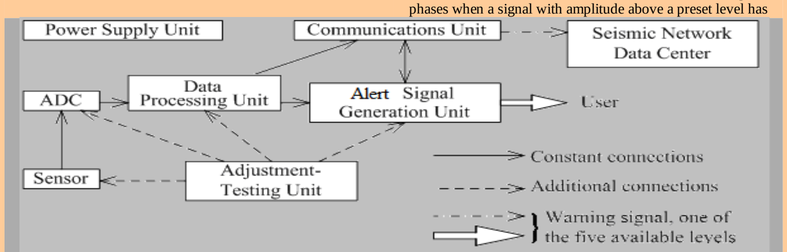

Fig. 1. Simple connection of a "single sensor" to the seismic network involved in earthquake warning

The data processing unit detects the onsets of P and S waves from earthquakes. Its functional elements are shown in Fig. 2.

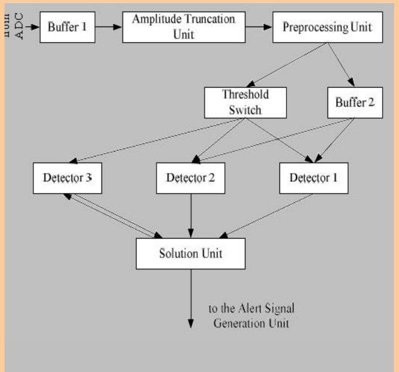

Fig. 2. Block diagram of the seismic data processing unit

Buffer 1 stores a portion (1024 values) of seismic data to be processed. The buffer is reset every second by shifting and by adding a new data portion.

The amplitude truncation unit disables the detection system when the ADC higher bits are filled. This means that strong shaking is occurring corresponding to destructive earthquake waves or else that the operation of either the sensor or the ADC has been disturbed. In that case the detection of low energy phases becomes meaningless and the detection is disabled.

The preprocessing unit removes the low frequency component and the constant component, filters and rescales the signal.

The threshold switch starts the detection of earthquake phases when a signal with amplitude above a preset level has appeared, thereby eliminating false alerts due to smaller or teleseismic events.

Buffer 2 stores the data which are required to determine the signal characteristics required in the first and second detectors.

Detector 1 finds the parameters of the preceding 10-second data interval and the parameters of the current 4 seconds of the signal. The next step is to compare these parameters and to detect earthquake phases using the adaptive algorithm for detecting low amplitude seismic phases which relies on time series analysis theory.

Detector 2 is based on a similar principle of operation; it detects earthquake signals by finding a change point in a random process and detecting signals in a moving time window. The χ^2 detector is computed. The detector responds to a change (compared with the noise power spectral density) in average power and average spectral density of the observations in the moving window. We note that a change in the spectral power density of observations is "caught" in the optimal way according to the asymptotic quality criteria.

Detector 3 generates feature vectors based on the current four-second data window. An artificial neural network is used in this case as the classifier. This aids to detect earthquake phases and to determine which phase is the signal.

The solution unit compares the detection results and generates an alert signal with an estimated level of the probability of that event. If the decision that a P wave has been detected is taken, then a signal is handed on to Detector 3 to adjust the latter so it will detect the S wave within a time interval estimated from the approximate magnitude and epicentral distance. If no S wave has been detected within the time interval thus determined, then a call-off signal is generated.

The block diagrams are given in a simplified form. We do not show the units for indication and self-adjustment of the system. The processing unit does not contain as indicated the module for calculating the earthquake parameters.

However, the signal received by the block diagram Figure 1, is of little value for early warning network.

In order to enable self-contained operation for the system and to incorporate it in the earthquake warning system as a station in its full right it is necessary to make the processing unit more complex (see Fig. 2). The block diagram for the modified seismic signal processing unit can be seen in Fig. 3. Subsequent to the solution unit it is necessary to add a unit for data recovery in which an earthquake signal is detected and synthesized in noise-free form. The synthesis is carried out by recovering the filtered wavelet transform of the signal [*Gravirov et al.*, 2010].

The earthquake parameters unit calculates the station-epicenter azimuth, epicentral distance and depth of focus, magnitude, intensity of shaking, and the uncertainties for these quantities. One should naturally incorporate knowledge of local seismicity and local geology that are required for determining wave attenuation and for estimating the P-S time interval as a function of epicentral distance. There are several procedures to determine earthquake parameters [*Hoshiba*, 2009].

Fast estimation of the earthquake parameters through detailed classification using wavelet transforms and neural networks is also possible. These methods can handle signals that are severely contaminated with noise. The values of earthquake parameters are transmitted to the warning signal generation unit and further to the seismic network data center via the commutation unit. A warning signal for a concrete user can in that case be obtained either from the warning signal generation unit or from the data center. The warning becomes more accurate thereby and can be received before the sensor records the P wave, provided the epicenter is distant enough. This justifies the additional expenses to be incurred by the user to install the sensor.

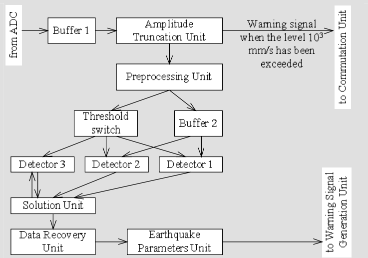

Fig.3. A block diagram for the modified seismic signal processing unit

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References:

1. *Wu Y.M., Kanamori H.* Experiment on an onsite early warning method for the Taiwan early warning system // Bull. Seismol. Soc. Am. 2005; v. 95; no. 1; p. 347-353.
2. *Kanamori*, (2005) Real-time seismology and earthquake damage mitigation // Annual Review of Earth and Planetary Sciences, 33 . pp. 195-214.
3. *Gravirov V.V., Kislov K.V., Ovchinnikova T.V.* An Adaptive Algorithm for Detection of Onset Times of Low Amplitude Seismic Phases Based on Time Series Analysis // Eos Trans. AGU, Fall Meet. Suppl., Abstract S53A-1956, San Francisco, USA, 2010.
4. *Hoshiba M.* Effect of time window length for maximum amplitude estimation on P wave magnitude: Application for Earthquake Early Warning // Eos Trans. AGU, Fall Meet. Suppl., Abstract S13A-1722, San Francisco, USA, 2009.