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The Friuli automatic earthquake alert system

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Abstract. An automatic alert system has been developed at the Friuli-Venezia Giulia seismic network (NE Italy) able to notify rescue organisations and scientific institutions the hypocenter coordinates and magnitude of local or close earthquakes in real-time. The system architecture has been structured into three main functional modules devoted to: data analysis, alert decision making and final result communication. A number of signal processing tasks are performed to evaluate focal parameters and conditions for alerting, among which, an original S-picking technique effective in improving localisation of earthquakes occurring up to 200 km from the centre of the network. A composite communication strategy has been implemented, which takes into account different alert levels, communication modalities (e-mail, fax and WWW pages) and receiver classes (including both human beings and remote software modules), and comprises also the ability to send updates as new data are acquired. Finally, the system supports the revision and refinement of the analysis by the seismologist through a graphical interface.

1. Introduction

In the last decade a number of systems for automatic real-time analysis of seismological data have been developed for either alert notification or automatic bulletin production (e.g. Bache et al., 1993; Kradolfer, 1993; Gee et al., 1996). The evolution of data acquisition systems together with the availability on modern computer of standard communication facilities and software packages of public domain has drastically reduced the time and costs required to develop such systems as well as increased their portability. It has also been made possible to extend their capabilities to include a more elaborated communication strategy and a higher level user interface for automatic result analysis and revision.

FAAS (Friuli Automatic Alert System) is an automatic alert system developed by and cur-

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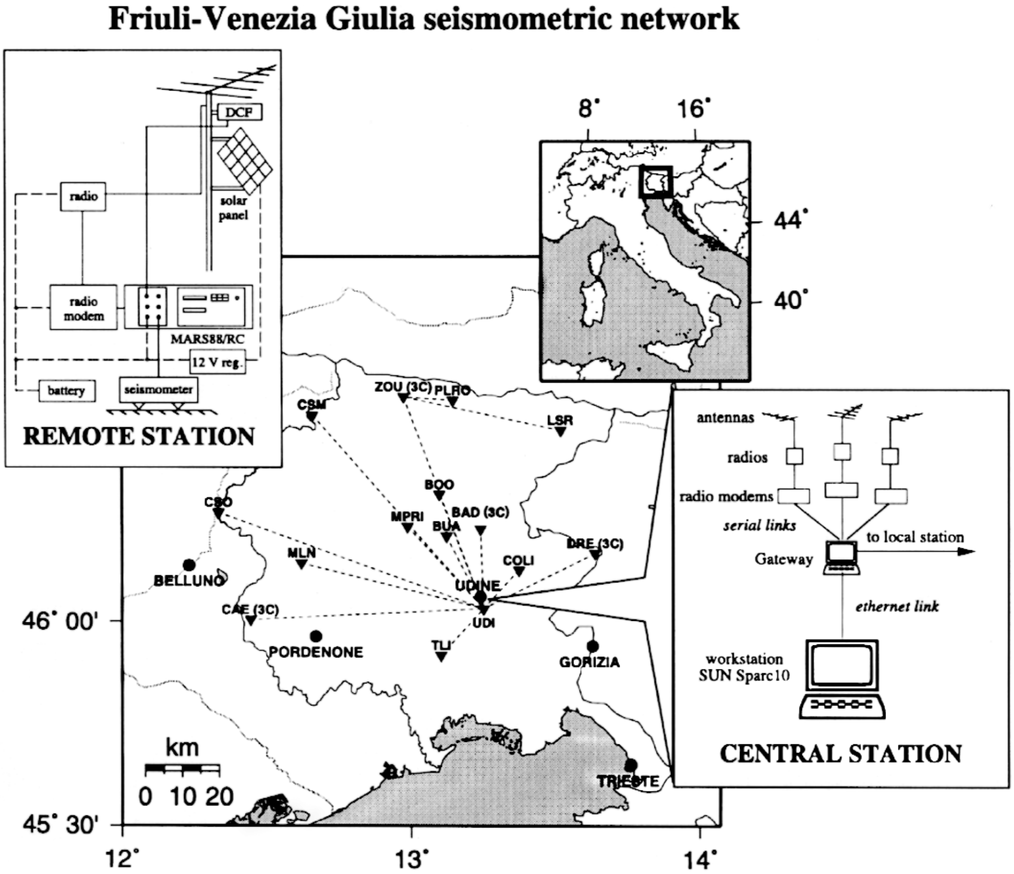


Fig. 1 - Topology of the Friuli-Venezia Giulia seismometric network and data acquisition hardware. Three component stations are marked “3C” on the map.

rently in use at the Friuli-Venezia Giulia seismometric network (Fig. 1). The network is located in the north-eastern part of Italy and managed by the Istituto di Oceanologia e di Geofisica Sperimentale (OGS).

Basically, FAAS communicates focal parameters about serious earthquakes which may be felt or located within the monitored region to authorities as well as to other scientific institutions. The following features have been elaborated for this purpose:

- the ability to interface to the acquisition system to access data for processing;
- automatic data analysis to evaluate hypocenter coordinates and magnitude of the earthquake as well as other alerting conditions. An original S-picking technique is applied among the processing steps;
- communication of results by taking into account different alert levels, communication modalities and receiver classes;
- dynamic revision of system conclusions as new data are acquired;
- human/computer interaction for manual revision and refinement of results produced by the auto-

matic analysis.

Communication features play a fundamental role in FAAS. A number of communication modalities have been taken into account (e.g. fax, telephone, e-mail, remote graphic interfaces, WWW pages), while classes of receivers have been defined to include both human beings and remote software modules or “clients”. Non-experts in seismology have been considered among the human receivers (e.g. the personnel of a civil protection operation centre), implying the definition of clear rules for alerting as well as the tailoring of messages on the receiver.

By taking software clients into account, the evolution of the system towards distributed solutions has been made possible. A general communication scheme has been devised such that new features may be added in the form of independent, loosely connected modules which interact with the “core” of FAAS through the exchange of e-mail messages having a standard format. At present, two such clients have been implemented, that is, an automatic WWW page updater, which modifies on-line seismic maps as new earthquakes are automatically located, and a remote graphic interface to browse and visualise alert notifications; the latter being installed at the regional rescue organisation headquarters.

As we will see, the characteristics of the telemetry make the delay in data acquisition potentially unpredictable. Then, a dynamic approach to communication was adopted, meaning that the alert system has been made able to judge the sufficiency of data acquired at a given time to guarantee a reliable solution. Furthermore, it has been made able to update and correct its own conclusions as new data are acquired, as well as to decide if updates are important enough to be notified (i.e., to avoid confusion and useless communication, only substantial variations in location and magnitude estimation are actually notified).

After a brief description of both the seismometric network and its acquisition system, the functional characteristics and implementation details of FAAS are presented below.

2. The Friuli-Venezia Giulia seismometric network

The seismometric network and acquisition system features impose constraints on the design of an automatic alert system. The Friuli-Venezia Giulia Seismometric Network (Fig. 1) is a local network covering the NE part of Italy which was struck by a destructive earthquake in 1976 (May 6, M_L =6.4). Its diameter is of about 100 km and consists of 15 stations, 14 of which are radio connected to the acquisition centre in Udine. The fifteenth station (UDI) is situated at the central station itself. Of the 15 stations, 11 are equipped with a vertical 1Hz seismometer while 4 (marked “3C” in Fig. 1) are equipped with a 3-component 1Hz seismometer.

A MARS88 system by Lennartz Electronic acquires data. This is an integrated hardware/software system supporting digitalisation and radio transmission of data, recording them on a signal database as well. At the remote stations, it comprises (see also Fig. 1) a MARS88 recorder acting as a digitizer and data processing unit, a radio-modem, a bi-directional antenna, a DCF receiver for clock synchronisation as well as solar panels and batteries for power supply. The MARS88 unit has been set to sample at 125 Hz on two stations (ZOU and BAD in Fig. 1) and at 62.5 Hz on the remaining ones. It has a dynamic range of 120 dB, a sensitivity of

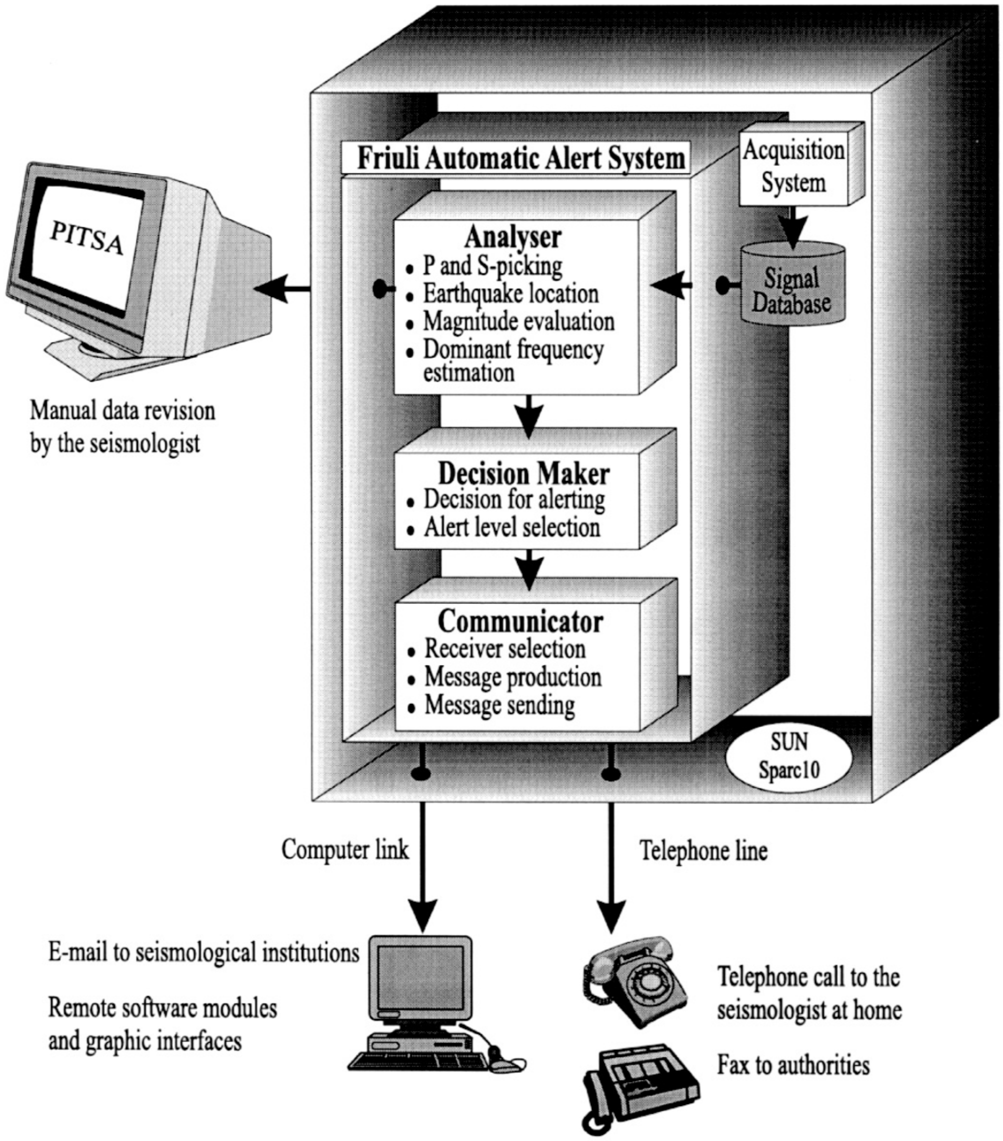


Fig. 2 - The architecture of the Friuli Automatic Alert System.

2 μV per LSB (Least Significant Bit) and an antialias low-pass filter at either 50 Hz (for stations sampled at 125 Hz) or 25 Hz (for stations sampled at 62.5 Hz). It stores samples as 16-bit words in a 4 Mbyte RAM memory and runs an STA/LTA algorithm to recognise sudden soil velocity changes, possibly caused by an earthquake. Corresponding samples plus a suitable pre- and post-event time interval are then marked as “triggered”, thus made eligible for transmission.

At the central station the acquisition system includes a workstation Sun Sparc10 running software for acquisition, management and access of data for on-line analysis. A PC running the UNIX operating system acts as a “gateway”, that is, as an interface between the workstation and the radio network. It is connected to the workstation through an ETHERNET local area network and to 3 radio modems by means of serial ports. A further serial port is devoted to a direct (wire) connection to the MARS88 which records data from the seismometer located by the acquisition centre.

Radio communication between the central and remote stations is digital and bi-directional. It is based on the exchange of data blocks or “packets” containing seismological data, status information or commands. In order to minimise the number of radio frequencies needed, remote stations are organised into three groups, each group sharing the same radio frequency on the basis of a “token passing” mechanism. Furthermore, to avoid data corruption, an error detection and data retransmission mechanism has been implemented.

Data acquisition is governed by the central station, which cyclically (once a minute) asks remote stations for status information. If a remote station signals a “trigger” condition, “triggered” data from that station are acquired. The central station may also decide to acquire data from the entire network for a given time interval if a coincidence of “trigger” conditions arises among a given (programmable) number of stations (4 in the present network setting).

The relative complexity of the communication protocol added to the intrinsic narrow band of radio links, lead to a delay in data availability at the central station. Though in typical cases it takes from 4 to 6 minutes to get enough data for earthquake location, such a delay is not a priori predictable. In fact, it depends on overall data traffic (i.e. on the number of stations “triggered” by a given earthquake) as well as on transient noise disturbing radio communication. This situation imposes a dynamic approach to data analysis and alert notification mentioned in the introduction.

3. System architecture

FAAS has been designed with the architecture depicted in Fig. 2. It is composed of three modules, namely the Analyser, the Decision Maker and the Communicator. They were written using the C language and implemented as independent UNIX processes communicating through standard files and running on the same machine as the one for data acquisition. The Analyser is the core of the system: it interfaces the on-line seismic database compiled by the acquisition system, extracts traces, performs all the numerical data analysis and produces a number of results which are sent to the Decision Maker in order to evaluate the possible alert situation and its attention level. Such a decision is then forwarded to the Communicator, which, considering the alert level and the pre-defined classes of receivers, produces suitable messages which are spread through various communication channels. Furthermore, all data produced by the Analyser are made available to the seismologist by means of the programme PITSA (Scherbaum and Johnson, 1993) as well as other graphic tools. Each module will be discussed in detail in the following.

3.1. The Analyser

The Analyser checks the signal database each minute. If new data, referring to the last hour, have been acquired, it verifies the presence of significant events through a coincidence algorithm that searches for concurring recordings from at least four stations. For each event it loads traces into the main memory to perform P and S phase picking, to locate the earthquake, to estimate its magnitude and dominant frequency. Results are communicated to the Decision Maker through a report file. The same event may be processed more than once as new data are acquired, which generates a sequence of report files recognised as further updates by the Decision Maker.

P and S-picking relies on original solutions which will be discussed in detail below. Earthquakes are located by use of the programme HYPO71 (Lee and Lahr, 1975). A duration magnitude (M_D) and an amplitude magnitude (M_L) are evaluated. In both cases the magnitude for the event corresponds to the mean of the magnitudes estimated on each trace. M_D is computed according to the formula by Rebez and Renner (1991)

$$M_D = a \log(\tau) + b + c\Delta \tag{1}$$

where τ is the signal duration in seconds, Δ is the epicentre-station distance in km, while a, b and c are coefficients depending on the station and obtained by regression analysis on a large set of earthquakes.

M_L is computed by applying the classical formula by Richter (1935)

$$M_L = \log(A) - \log(A_0(\Delta)) \tag{2}$$

where A is the maximum amplitude (in mm) recorded by a Wood-Anderson seismometer and -log (A_0 (Δ)) is a term which takes into account attenuation of the signal with distance Δ. The eval-uation of M_L involves three main steps:

- simulation of Wood-Anderson seismograms from velocity seismograms: it is a classical problem in seismology discussed, for example, by Bakun et al. (1978) and Urhammer et al. (1996). For FAAS the numerical routine by Tento (1995) has been used;
- vertical to horizontal transformation: it is needed because the Wood-Anderson seismometer is an horizontal one, while much of our sensors are vertical. For this purpose, the solution by Alsaker et al. (1991) has been adopted. A set of signals from available three-component seismometers have been considered to establish, by linear regression, the relation

$$\log(A_H) = 1.02 \log(A_V) + 0.12 \tag{3}$$

between the logarithms of the vertical and horizontal maximum amplitudes A_V and A_H. Such relation is then used as a correction formula for the vertical seismometers of the network;
- use of an attenuation law calibrated for the region: at present, values for -log (A_0(Δ)) are taken

from the original paper by Richter. For the future, we intend to calibrate the M_L scale for the Friuli-Venezia Giulia similarly to that proposed by Bakun and Joyner (1984) and Alsaker et al. (1991).

P-PICKING. - P-wave arrival times are determined using the algorithm by Baer and Kradolfer (1987). As such an algorithm is a single-trace one, it is unable to exploit time constraints derived from recording the same event from a number of stations. Thus, a procedure, based on a preliminary earthquake location, is applied in order to verify coherence among picks, discover major errors and, if possible, correct them.

The cross-checking and correction scheme works on the basis of the empirical observation: given a set of picks, including a number of reliable picks and few erroneous ones, reliable picks may be distinguished as they have similar (even high) residuals in a location based on r.m.s. (rooted mean square) minimisation, whatever the quality of the location. As an example, let's consider the set of picks

$$(p_1,\ p_2,\ p_3,\ p_4,\ p_5,\ p_6,\ p_7,\ p_8,) \tag{4}$$

having residuals (in seconds)

$$(-6.4,\ -5.1,\ -0.1,\ 1.5,\ 1.7,\ 2.2,\ 2.3,\ 4). \tag{5}$$

One may suspect the arrival times p_1, p_2 and p_8 as being wrong, as their residuals are very high. Obviously, there is the possibility that one or more of them are correct while all the others (from p_3 to p_7) are wrong, but we retain such an hypothesis as highly improbable. The arrival times from p_4 to p_7 also have high residuals, but they appear to be coherent among themselves. So, we can suppose that they are correct and their high residuals are due to the attempt of the location algorithm to mediate between wrong and right picks. If we accept such hypothesis, the arrival time p_3 is also incorrect. In fact, its residual, even if low, is very far from that of the correct picks. In the light of such considerations, the error detection and correction procedure assumes the largest set of picks whose residuals are within a 2 s time window (p_4, p_5, p_6 and p_7 in the example) as reliable. The remaining picks are considered erroneous, therefore corresponding seismograms are re-picked on the portion of signal preceding or following them, depending whether they appear to be late (e.g. p_8) or early (e.g. p_1, p_2 and p_3) by comparison to the correct set. Re-picks are then considered to be reliable for location if their residuals fall in the 2 s time window defined by the original set of correct picks, otherwise they are definitively discarded.

The method works in the hypothesis that the number of erroneous picks is low with respect to the total number of picks (e.g. 1 or 2 over 6 or more), which, in practice, is the more common situation. Furthermore, it has proved to be effective in discovering and correcting only major errors (in the order of 1 second) caused by either spikes or sudden variations in the noise level.

S-PICKING. - An S-picking algorithm has been devised to improve location for events occurring externally to the network, in the range of 200 km from its centre, which corresponds to a maximum station-epicentre distances of 250 km (we wish to recall that the network has a radius of

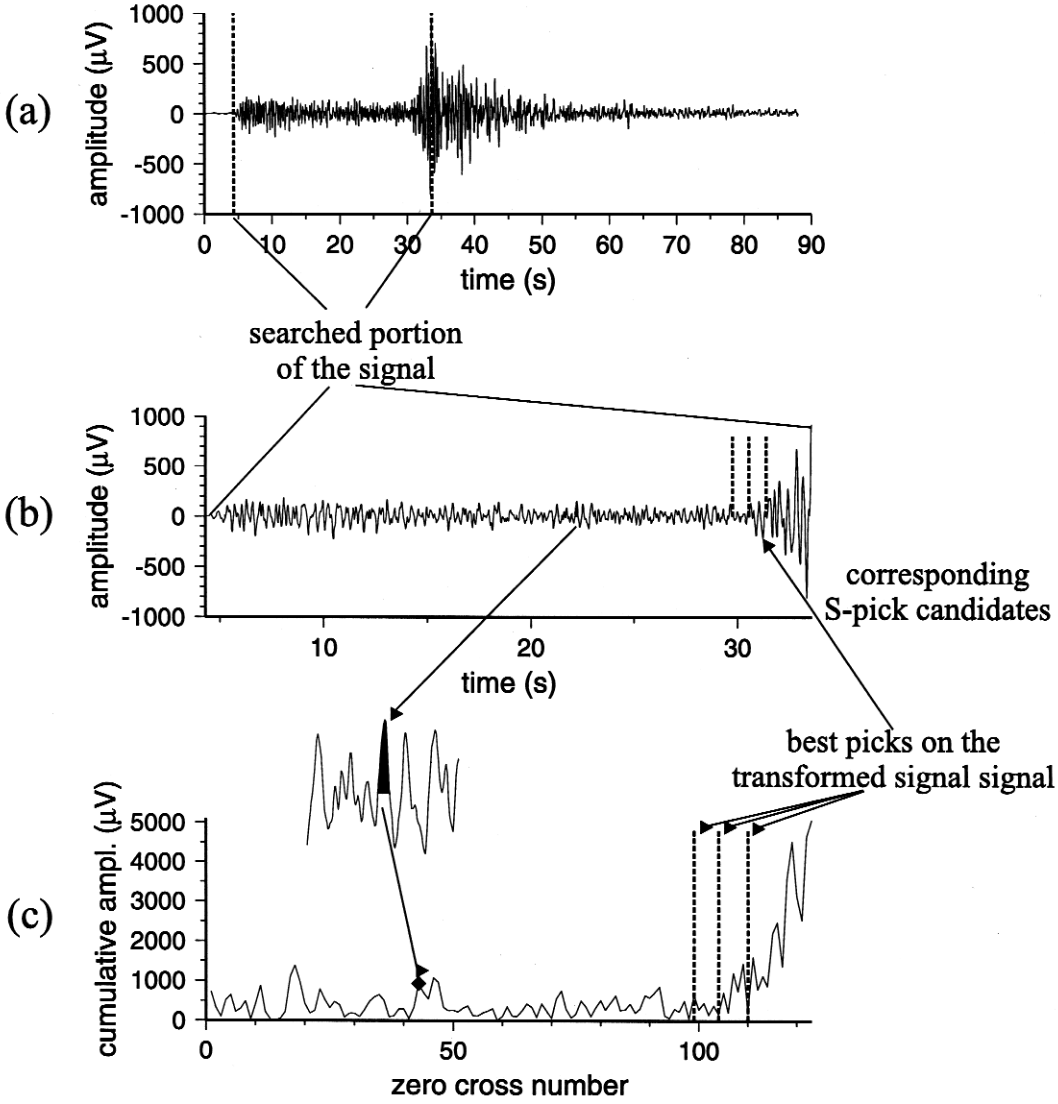


Fig. 3 - Representation of signal transformation and S-picking on a single seismogram. Of the original signal (a), only the portion between P-onset and the maximum is taken into account (b). A signal transformation is then applied (c) which at each zero-crossing associates the area beneath the curve of the signal up to the next zero-crossing. Based on STA/LTA evaluation at each point, the best three picks are detected on the transformed signal. Corresponding zero-crossing constitutes S-pick candidates for the original signal.

about 50 km). For such events, the location, if based on just P-picks, is commonly incorrect. Much of the error is due to the poor determination of the distance from the network, while the computed direction is usually reliable. Information about distance deriving from P and S arrival time differences is then decisive in getting a reliable location.

As we will see, the method recognises the S-phase (assumed to be an Sg) as the strongest

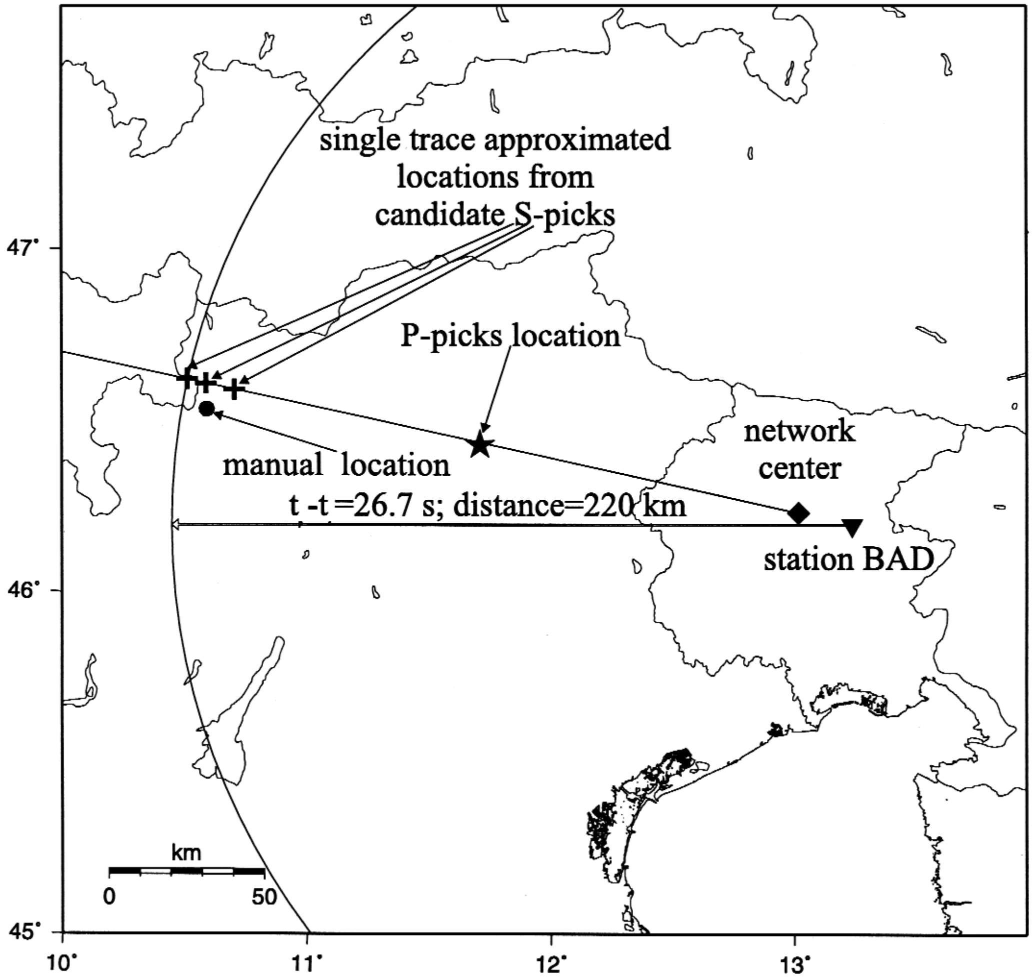


Fig. 4 - Single-trace approximate locations for the three candidate picks of Fig.3. Distance from the station is estimated from the S-P arrival time difference, while the direction is obtained by joining the centre of the network to the epicentre computed by HYPO71 using just P-picks. The manual location from the OGS bulletin (OGS, 1995-1997) is also represented as a small solid circle. Its radius corresponds to the horizontal error computed by HYPO71 (2.4 km in the example).

variation in the signal, after the P arrival. Then, it may fail if other phases (e.g. Pn and Sn) are present in the seismogram. Such phases start emerging at station-epicentre distances of about 200 km, but, in practice, we have observed that Sg remain predominant at least up to 250 km.

The method, which needs P-picks as a prerequisite, works in two steps. As a first step, a basic single-trace algorithm is applied to each horizontal channel in order to detect a number of possible S-picks (the “candidates”). Such algorithm relies on a transformation of the seismogram that emphasises S-phase onsets. It is inspired by manual analysis, where seismologists recognise the S-phase arrival time as the increase in amplitude and period of the seismogram, both contributing to an increase of the area beneath the curve of the signal in a semiperiod. Then,

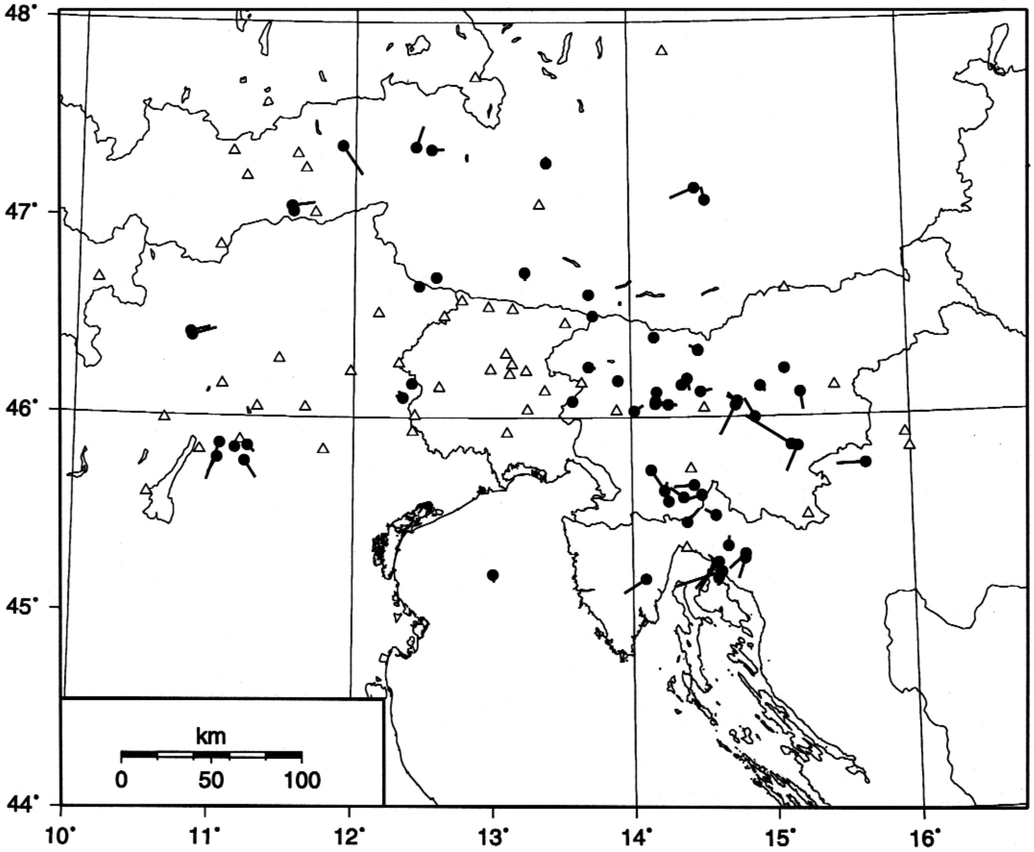


Fig. 5 - The set of events used to test the S-picking method. Solid circles represent manual epicentres; segments link manual and automatic locations to give a visual estimation of the error by the automatic system; finally, triangles represent stations considered for manual locations. The set consists of 64 events which occurred externally to the OGS network up to 200 km from its centre and having a duration magnitude of between 2.8 and 3.8. They were recorded in the period January '95-January '97 by at least 5 OGS stations, 2 of which were three-component ones. Manual locations were taken from the OGS bulletin (OGS, 1995-1997) and have HYPO71 horizontal error of less than 3 km.

given the original signal with the offset removed, $x(k)$, and, its j-th zero-crossing z_j, (i.e. the j-th sample for which $x(z_j)\geq 0$ and $x(z_j+1)<0$ or vice versa), a transformed function, $y(j)$, has been defined (Fig. 3). At each zero-crossing it associates the area beneath the curve up to the next zero-crossing, that is:

$$y(j)=\sum_{k=z_j}^{z_{j+1}-1}\left|x(k)\right|. \tag{6}$$

Sudden changes in $y(j)$ are then detected on the basis of an STA/LTA criterion. Search is restricted to the interval corresponding to the portion of $x(k)$ between the P-phase onset and the maximum of $x(k)$ itself. The three best picks in $y(j)$ (i.e. the ones for which the STA/LTA ratio is the highest) are selected. The corresponding zero-crossing in $x(k)$ are identified as possible S-

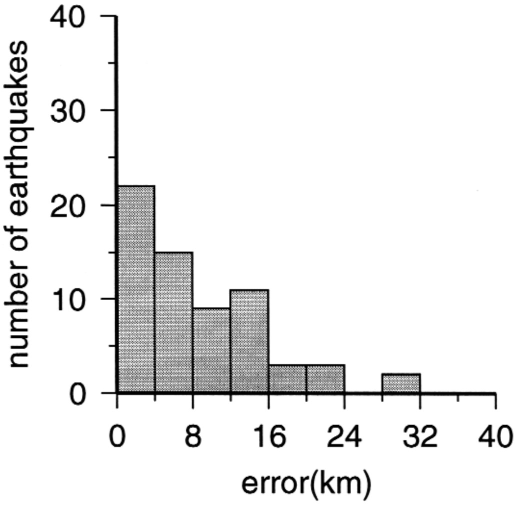


Fig. 6 - Distribution of differences between automatic and manual locations. It has a mean $\mu = 8.70$ km, a standard deviation $\sigma = 6.68$ km and a maximum of 29.83 km.

arrivals and are assigned the STA/LTA ratio evaluated on $y(j)$ as a weight. For each candidate, an epicentre for the earthquake is also computed by considering (see Fig. 4), as the station-epicentre distance, the one obtained from the S-P arrival time difference and, for the direction, the one from the centre of the network to the P-picking HYPO71 epicentre. We term such single trace location as "approximate" to distinguish it from the "precise" location computed by the alert system at the end of the picking phase, running HYPO71, with all the selected (P and S) arrival times.

The second step in the S-picking algorithm selects the best candidate from each trace as the one that better agrees with candidates from other traces. For this purpose all the n-tuples consisting of one candidate from each horizontal channel are considered. For each n-tuple the centroid of the corresponding single-trace approximate epicentres is computed. The most reliable n-tuple is then selected as the one which maximises the weight

$$w = \frac{\sum_{i=1}^{N} w_i}{\sum_{i=1}^{N} d_i} \tag{8}$$

where N is the number of candidates constituting the n-tuple, w_i represents the weight of the i-th candidate (i.e. the associated STA/LTA ratio from the single trace picking) and d_i is the distance of the corresponding approximate epicentre from the centroid, computed for the n-tuple. In such a definition the quality of an n-tuple grows with the reliability of its picks and is inversely proportional to the scatter of the corresponding approximate epicentres. Elements of the best n-tuple constitutes the final S-picks for the horizontal traces.

Effectiveness of the method was initially tested on a set of 64 events being up to 200 km from

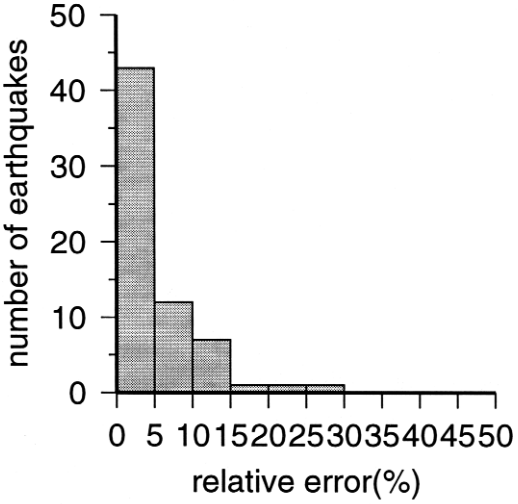


Fig. 7 - Distribution of relative errors in location. They have been estimated as the ratio between the automatic-manual location difference and the distance of the manual epicentre from the centre of the network. The distribution has a mean μ = 6.58% and a standard deviation σ = 4.20%, while 55 events (84.6%) have a relative error lying within 10%.

the centre of the network (Fig. 5). Automatic epicentres were matched against corresponding manual locations taken from the bulletin of the network (OGS 1995-1997). Thanks to the higher quality of manual picks and the better azimuthal coverage of events, due to the use of data from stations of neighbouring networks (also shown in Fig. 5), manual locations are assumed to be much more reliable than the automatic ones. In particular, all manual locations considered for the test have an horizontal error, computed by HYPO71, of less than 3 km. Then, the differences between the automatic and manual epicentres can be taken as an estimation of errors in location by the automatic system.

The distribution of such differences is shown in Fig. 6. It has a mean μ = 8.70 km, a standard deviation σ = 6.68 km and a maximum of 29.83 km. The relative error is also of interest, as we can tolerate an higher error with increasing distance. It has been estimated as the ratio between the automatic-manual location difference and the distance of the manual epicentre from the centre of the network. Distribution of such estimations is shown in Fig. 7. It has a mean μ = 6.58% and a standard deviation σ = 4.20%, while 84.6% of automatic locations have a relative error lying within 10%; a result we consider to be satisfactory for rapid alert purposes.

3.2. Decision Maker

On the basis of the report file produced by the Analyser, the Decision Maker evaluates the current state of information (i.e. if data are enough to guarantee stable results), classifies the event, evaluates its local interest and then decides about the alert level. Furthermore, it is able to recognise data from the Analyser as significant updates for a previously notified event and to decide on the need for retransmission of the alert messages.

An event is taken into consideration and its parameters are regarded as stable if a 60-second signal and the corresponding P-wave arrival time are available for at least four stations. Two S-wave arrival times are also required for events occurring externally to the network.

In order to discriminate between close and distant events, following Chiaruttini et al. (1989) we have adopted the rule

if

$$\log\left(A_{\max}\right) < -2\ \log\left(f_{dom}\right) + k_d \tag{8}$$

then

the event is distant

where A_{max} is the maximum amplitude of the trace (we use the simulated Wood-Anderson maximum amplitude), f_{dom} is its dominant frequency and k_d is a parameter depending on the chosen discriminating distance. We apply (8) to each trace and take, as valid, the conclusion on which the majority of traces agree. The rule assumes that, for any event at distance d from a station, A_{max} and f_{dom} increase and decrease respectively with magnitude and, that their logarithms are related by the linear equation

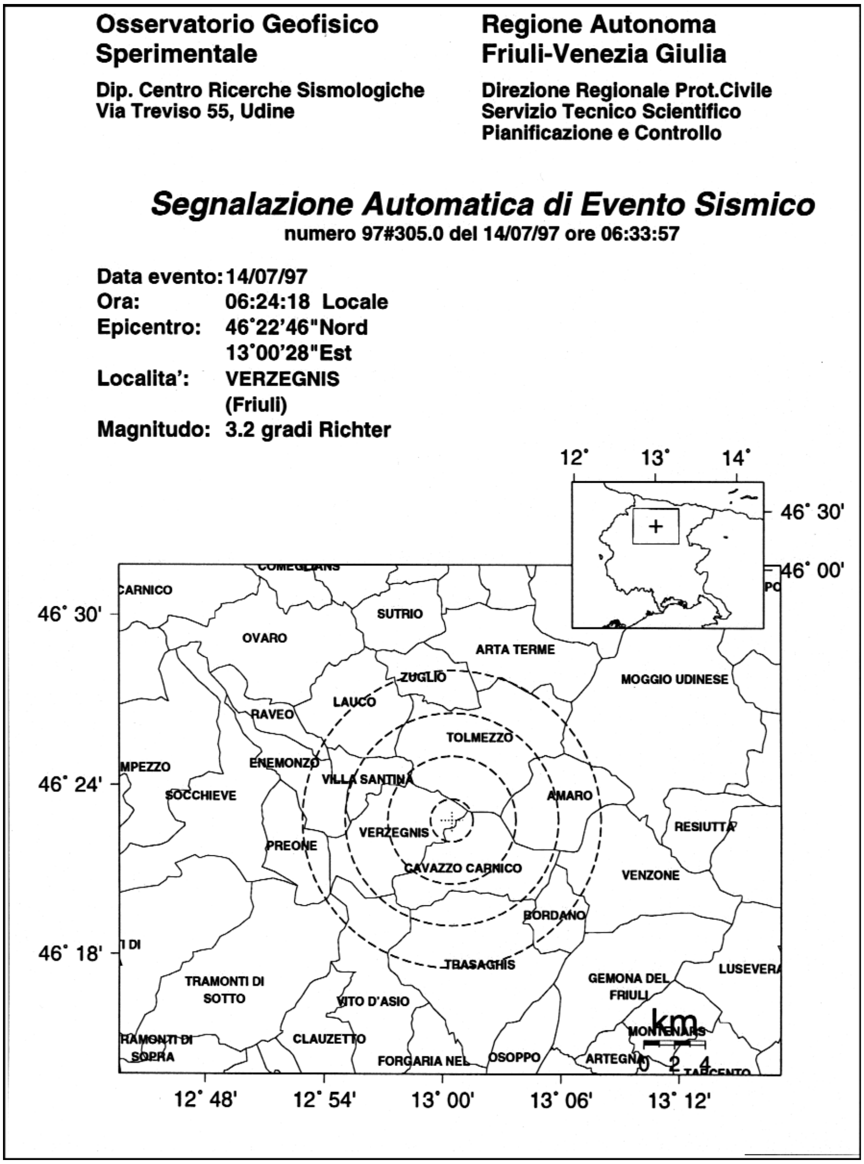
$$\log\left(A_{\max}\right) = -2\ \log\left(f_{dom}\right) + k_d. \tag{9}$$

Furthermore, as both A_{max} and f_{dom} decrease with distance, it is expected that for d'>d it is $k_{d},<k_{d}$ and then that the corresponding points (log A_{max}, log f_{dom}) corresponding to *d'* is placed in the halfspace defined by the inequality in (8). Concerning the value of k_d adopted in (8), based on empirical considerations and on the analysis of few distant events, we have chosen the value 2.5, which in our case corresponds to a discriminating distance of about 250 km. Though very crude, this criterion is useful to identify events which are surely out of local interest and whose focal parameters cannot be determined reliably. In such a case only P-picks are transmitted to other seismological institutions.

In the case of local or close events, the significance of the earthquake for the monitored region is evaluated. Local rescue organisations are interested in all the earthquakes that may be felt by the population of the Friuli-Venezia Giulia region. Based on our experience, we have decided to transmit to them all the events, internal to the region, having a magnitude greater or equal to 2.8. Furthermore, we signal events external to the region for which at least one station gives a simulated Wood-Anderson maximum amplitude greater or equal to 25 mm. According to the attenuation law by Richter, the criterion corresponds to having at least one station (and then one place in the region) that has “felt” the earthquake in the same way as an earthquake of magnitude 2.8 or greater occurring just below it.

Based on previous analyses, a suitable alert level among the following three is chosen:

- level 1, or OGS internal alert. Such level is set for non-significant earthquakes for which a location exists. It involves alerting the OGS staff only via e-mail;
- level 2, or scientific interest alert, corresponding to distant earthquakes for which a reliable



Osservatorio Geofisico Sperimentale

Dip. Centro Ricerche Sismologiche
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Regione Autonoma Friuli-Venezia Giulia

Direzione Regionale Prot.Civile
Servizio Tecnico Scientifico
Pianificazione e Controllo

Segnalazione Automatica di Evento Sismico

numero 97#305.0 del 14/07/97 ore 06:33:57

Data evento: 14/07/97
Ora: 06:24:18 Locale
Epicentro: 46°22'46"Nord
13°00'28"Est
Localita': VERZEGNIS
(Friuli)
Magnitudo: 3.2 gradi Richter

Fig. 8 - An example of a fax message which is sent to authorities in the case of significant earthquakes of local interest.

location is not available. In that case, an e-mail message including just P-picks is sent to other seismological institutions in Italy (e.g. the Istituto Nazionale di Geofisica (ING) in Rome) and neighbouring countries (e.g. LDG in Paris, which is the institution that manages the rapid location system of the European-Mediterranean Seismological Centre (EMSC));

- level 3, or "general alert", corresponding to local or close earthquakes having local significance, for which every known recipient is notified.

Alert messages are submitted to the Communicator for transmission only in the case of new events or substantial updates for previously notified events. On deciding what is a "substantial update" we have tried to mediate between the opposite requirements for precision of data and a low number of messages. Then, after a trial period, we have chosen, as relevant, the adjustments of at least 2 km for the location and 0.2 units for the magnitude, so that in typical cases one update at most is expected.

3.3. Communicator

This is the module devoted to the generation of messages as well as to their routing along the right communication channel according to the alert level and the corresponding class of receivers selected by the Decision Maker.

As said above, alerts at level 1 and 2 involve just e-mail notification. For earthquakes having alert level 3, a map representing the epicentre (Fig. 8), including focal parameters, is sent via fax to authorities as well. Furthermore, in the case of important updates that need to be communicated, messages include a complete reference (date, time and serial number) to the previous fax. For the same alert level a structured report file including a complete description of the event is sent via e-mail to the remote software modules, which in turn implement further communication modalities (at present WWW pages and a specialised graphic interface, both described in the following). Finally, during the night and on off-duty days, the Communicator places a telephone call to a seismologist at his home.

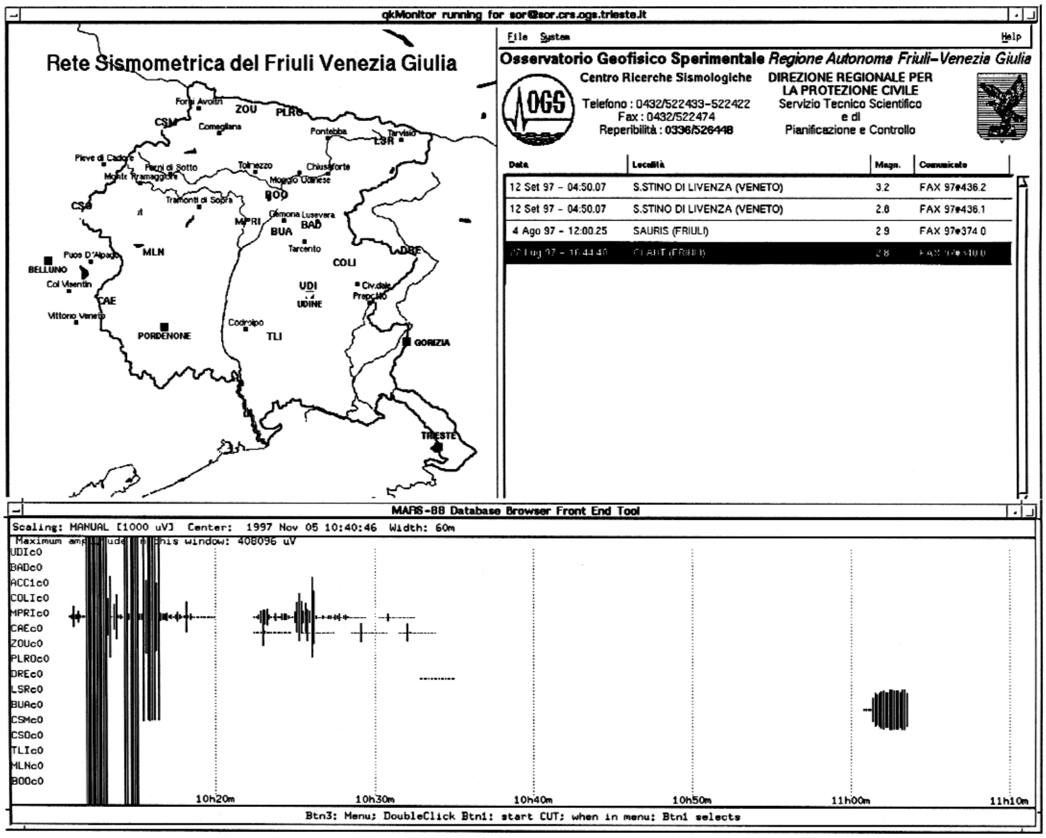
4. Software clients

At present, two software clients have been set up to receive e-mail alert notifications from FAAS to extend its communication capabilities.

The first client is a remote graphic interface named "qkMonitor" (Fig. 9). It has been written using the C programming language and MOTIF graphic libraries. It consists of three windows: a browser, to search among alert notifications; a map, on which selected epicentres are shown; and a monitor, which displays seismic traces as they are recorded. For a given alert notification, it is also possible to visualise the corresponding fax which has been sent to authorities from the browser. At present qkMonitor is installed at the operation centre of the local rescue organisation, that is the "Dipartimento di Protezione Civile" of the Friuli-Venezia Giulia regional administration. It may be installed at other centres in the future by simply updating a mailing list in the alert system.

The second client, still being tested, is an automatic WWW page updater which, given a new alert notification, should modify the HTML file corresponding to the page "Latest Earthquakes" of the OGS site at the address "http://www.crs.ogs.trieste.it". Furthermore, it should update the map reporting recent seismicity on the same WWW site.

Though different, the two clients have in common the same e-mail processing interface, which could be reused in the future to set up other modules. Such interface analyses the mes-



qkMonitor running for sor@sor.crs.ogs.trieste.it

Osservatorio Geofisico Sperimentale *Regione Autonoma Friuli–Venezia Giulia*

Centro Ricerche Sismologiche
Telefono : 0432/522433–522422
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DIREZIONE REGIONALE PER
LA PROTEZIONE CIVILE
Servizio Tecnico Scientifico
e di
Pianificazione e Controllo

Data	Località	Magn.	Comunicato
12 Set 97 – 04:50.07	S.STINO DI LIVENZA (VENETO)	3.2	FAX 97#436.2
12 Set 97 – 04:50.07	S.STINO DI LIVENZA (VENETO)	2.8	FAX 97#436.1
4 Ago 97 – 12:00.25	SAURIS (FRIULI)	2.9	FAX 97#374 0
[illegible]	CLAUT (FRIULI)	2.8	[illegible]

MARS-88 Database Browser Front End Tool

```
Scaling: MANUAL [1000 uV]   Center:  1997 Nov 05 10:40:46  Width: 60m
Maximum amplitude in this window: 408096 uV
```

```
Btn3: Menu; DoubleClick Btn1: start CUT; when in menu; Btn1 selects
```

Fig. 9 - The graphic interface of "qkMonitor", the remote software client installed at the local rescue organisation to browse among alert notifications and to monitor data acquisition.

sages addressed to a special user associated to the client, recognises alert messages thanks to a particular identifier, extracts information of interest and then passes it to the body of the client which implements its specific function.

5. System-seismologist interaction

The automatic alert system runs completely unattended. It processes data and sends alert messages to the recipients selected by the Decision Maker without human intervention. In particular, no operators are present at the acquisition centre during the night and on off-duty days. The seismologist intervenes only later, alerted by the system itself through an e-mail message or a telephone call at home, with intervention delays which go from a few minutes to an hour. At the acquisition centre she/he can interact with the alert system in order to analyse and refine its conclusions. In particular, after selecting the event of interest by means of a menu, the seismologist finds on the system console all the messages generated by FAAS: the report file produced by the Analyser as well as the epicentral map and the bulletin page produced by the Communicator. Furthermore, she/he finds a PITSA session opened on the traces of interest, including automatic P, S and signal duration picks.

By looking at the report file it is possible to judge the Decision Maker's conclusion about the reliability of focal parameters and the selected event class. Furthermore, by looking at the bulletin page it is possible to enter the details of the location process and decide on the quality of picks. If the results are not satisfactory, the seismologist can modify the picks by means of PITSA, re-execute the location procedure, as well as include the solution in the OGS bulletin.

6. Results

The system has been running since April 1996. In two years it has notified about 40 earthquakes at the alert level 3 (i.e., the one involving fax transmission to authorities) with magnitudes M_D ranging from 2.8 to 5.6. The typical response time has been about 10 minutes, measured from the origin time of the earthquake, up to the complete transmission of the first fax. Of this time interval, at least 6 minutes are needed to acquire enough data from remote stations. The updating of alert messages has seldom been needed for events at the alert level 3. On a few occasions just one updating message was sent about 5 minutes after the first notification.

The system proved its usefulness and reliability on the occasion of the earthquake which occurred on April 12, 1998 at 10:55:31 GMT ($M_D = 5.6$) in Slovenia, near the Italian border. The earthquake, the strongest in the area since 1976, damaged Bovec (VII - VIII EMS), Kobarid and Tolmin in Slovenia, while a limited effect was reported in Friuli. On this occasion the alert system located the event in 6 minutes, after which it started the communication procedure including fax and e-mail transmission. After 15 minutes a seismologist, alerted by telephone by the system itself, reached the central station to follow the on-going seismic sequence. Among the e-mail messages, one reached the Geophysical Survey of Slovenia and contributed to the evaluation of the event by the authorities of that neighbouring country. Seismometric data gathered by the acquisition system in six minutes were sufficient to generate a reliable location and magnitude estimation, so that no update was needed.

In other circumstances, also the notification of events at the alert level 2 (involving the sending of P-picks to seismological institutions) has shown to be useful. In fact, such picks have often been used by the Croatian and Slovenian networks. Furthermore, they are commonly taken into account by the EMSC to compute its rapid joint locations.

7. Conclusions

An automatic alert system which covers signal processing tasks as well as communication functions has been described. Compared to other, similar systems (e.g. the one proposed by Kradolfer 1993) which try to locate earthquakes based on P-picks all around the world, it concentrates on the reliable location of local and close earthquakes by using also S-picks; the latter being detected through an original technique. Communication features allow us to deal with a number of receivers which differ on the interest level as well as on the way they are connected to the system. In particular, software modules which receive alert messages may extend the capabilities of FAAS to satisfy the specific needs of the users. Furthermore, architectural and implementation choices have been made which should facilitate the porting of FAAS on other hardware platforms as well as its interfacing to other acquisition systems.

In common with Kradolfer (1993) FAAS has the idea of a system able to deal with different classes of recipients. Furthermore, his AUTODRM inspired us to implement loosely connected modules that communicate by e-mail according to a structured language. Ideas have been drawn also from Chiaruttini et al. (1989) who were the first to approach seismic signal automatic interpretation at the Friuli-Venezia Giulia network.

For the future, more elaborated interpretation techniques should be implemented (e.g. Joswig 1995) in order to recognise new event classes (e.g. explosions) and seismic phases, as well as to lower the detection threshold of the system. From such techniques we also expect to reinforce conclusions made from single trace analyses, which should improve system reliability in the case of problems in data acquisition.

The e-mail list for alert notifications is an open one. Organisations or researchers who are interested can subscribe to the alert system by sending an e-mail message to pbragato@ogs.trieste.it where they specify if they are interested in receiving only locations or phase arrivals for non-located events too.

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