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VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

QUARTERLY REPORT NO. 4

1 JULY 1977 TO 30 SEPTEMBER 1977

TEXAS INSTRUMENTS INCORPORATED
Equipment Group
Post Office Box 6015
Dallas, Texas 75222

Contract Number: F08606-77-C-0004
Amount of Contract: $560,000
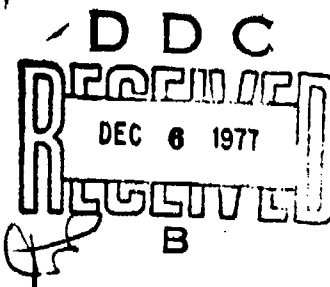Beginning 1 October 1976
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Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Program Code No. 7F10
ARPA Order No. 2551

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This fourth quarterly report summarizes progress under the VELA Network and Automatic Processing Research program, Contract Number F08606-77-C-0004, during the period 1 July 1977 to 30 September 1977. Work in the following areas is summarized:

- Evaluation of ILPA and SRO data
- Development of detection methods

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- Methods of extracting long-period event waveforms
- Interactive seismic signal processing
- Determining path corrections and extracting source parameters from long-period data.

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SECTION I

INTRODUCTION AND SUMMARY

This fourth quarterly report summarizes the progress made during the period between 1 July 1977 to 30 September 1977 in the VELA Network Evaluation and Automatic Processing Research program being carried out by Texas Instruments Incorporated at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The five program tasks are:

- Evaluate the performance of the Iranian Long Period Array (ILPA) and the Seismic Research Observatories (SRO)

- Develop advanced methods for detecting seismic events and evaluate the event detection capability of postulated networks of seismic detectors

- Extract long-period seismic event waveforms given the location and origin time of an event

- Develop and demonstrate function processes for interactive signal processing; standardize and automate the processing functions; also demonstrate their feasibility for the graphics processing of events

- Compute instrument and path corrected spectra of a network of long-period seismic sensors and estimate seismic source parameters.

The Research Objective Plan drawn up and approved for performing these tasks is approximately on schedule. During this quarter we completed the data analysis and interpretation for the above tasks and are now finalizing the preparation of technical reports, software demonstrations, and documentation.

For both the ILPA and SRO data evaluations, work was concentrated in the following areas:

- Expand the data base using the National Earthquake Information Service (NEIS) lists available

- Maintain data preparation software which is primarily the conversion of edit and beamform programs to the Terminal Support (TS) system

- Prepare software for extended noise analysis

- Perform the routine signal processing and analysis needed to evaluate each station separately and to evaluate all stations as a network designed to locate and measure earthquakes and presumed explosions.

To develop advanced methods for detecting seismic events, four research tasks are being pursued. These are as follows:

- Perfect and test methods for automatically timing the arrival of seismic events

- Determine the feasibility of using an adaptive beamformer to detect weak signals generated by seismic events

- Develop an automatic method to associate the detections of an event received at a sub-set of seismic stations and to predict the arrival times of event phases at all stations of the network

- Improve the efficiency and accuracy of estimating a seismic network's capability to detect and locate events of a given magnitude and from a given location.

To develop event waveform extraction techniques, two tasks are being performed as follows:

- Extract long-period bodywaves from edited single sensor three component data and from array data

- Cascade several methods of long-period event waveform estimations to optimize the extraction of weak signals.

To develop interactive graphics signal analysis capability, the following three tasks are being performed:

- Standardize seismic processing functions for performing discrimination analysis

- Extend the Interactive Seismic Processing System (ISPS) by developing a seismic programming language to generate displays. plots, and tables from data and information files stored on the disk, and to perform simple analysis functions on this data

- Develop software for transfering data to a mass store.

The final program task is to derive accurate transmission path corrections and source parameters from long-period data. This is broken down into three tasks as follows:

- Use newly developed and existing software for spectral analysis corrected for instrument response, path attenuation, and dispersion

- Form a suitable data base with long-period waveforms measured at a large number of stations providing adequate azimuthal coverage of the event

- Compare these to theoretical spectra and radiation patterns derived from the best fit source model as a means of estimating the source parameters associated with an event.

SECTION II

ILPA AND SRO EVALUATION

A. CURRENT STATUS

1. SRO

During the past quarter, we have completed the following points in the SRO evaluation:

- Routine processing of short-period and long-period signals and noise samples

- Basic analysis of the short-period and long-period data.

During this quarter we have also been engaged in analyzing the results of this evaluation and writing the evaluation report. In Tables II-1 and II-2 we present some samples of the results of this evaluation.

We note that in Table II-1 the differences in short-period (SP) RMS noise can be correlated with the distance between the individual stations and the nearest coastline. Albuquerque, New Mexico (ANMO), the station farthest from a coastline, shows the lowest SP RMS noise levels. From that point, as the distance between the station and the nearest coastline decreases, the SP RMS noise increases. This implies that the primary source of short-period seismic noise is wave energy injected into the crust at the coastline.

The long-period noise does not show this great station-to-station variation. There appear to be three groups of stations based on the level of LP RMS noise. The lowest levels are recorded at Albuquerque, New Mexico (ANMO); and Mashhad, Iran (MAIO); the next higher levels at Guam, Marianas Islands (GUMO), Narrogin, Western Australia (NWAO), and Taipei, Taiwan (TATO); and the highest levels at South Karori, New Zealand (SNZO).

TABLE II-1

MEAN RMS NOISE AT THE SRO STATIONS IN MILLIMICRONS

Station	Short-Period Vertical Component	Long-Period		
		Vertical Component	North Component	East Component
ANMO	0.38	9.56	8.66	9.76
GUMO	40.25	11.25	17.20	18.23
MAIO	0.57	8.20	7.89	8.19
NWAO	7.69	13.44	17.25	11.61
TATO	20.61	14.22	15.65	18.12
SNZO	28.92	45.92	27.26	30.17

TABLE II-2

SRO LONG-PERIOD DETECTION CAPABILITY
(50 PERCENT DETECTION THRESHOLD IN NORSAR m_b UNITS)

Type of Detection Statistics	50 Percent Detection Threshold All Eurasian Regions			
	ANMO	CUMO	MAIO	TATO
Mixed events, events for which no data were recorded, and events containing malfunctions are counted as non-detections	5.04	5.09	4.55	4.50
Mixed events, events for which no data were recorded, and events containing malfunctions are rejected from detection statistics	4.61	4.53	4.13	4.12

In the first category presented in Table II-2, we present what
we term the absolute 50 percent detection threshold. This is a 'real-world'
estimate of detection capability, since it takes into account the effects of
mixed events, failure of the station to record data, and system malfunctions
on the detection capability of each station.

The second category in Table II-2 presents the ideal 50 percent
detection threshold. In this case, the analyst can clearly determine the de-
tection status of every event investigated. We can see from these values that
mixed events, events for which no data were recorded, and malfunctions de-
crease the detection capability of the SRO stations by approximately 0.5
NORSAR m_b units. At present, we are determining the regionalized detection
capability of each SRO station using both short-period and long-period detec-
tion statistics. These will be presented and discussed in the SRO evaluation
report currently being written.

2.   ILPA

During the past quarter we have completed all routine process-
ing and almost all analysis of ILPA data. The specific areas covered include:

- Editing, beamforming, filtering, and plotting of ILPA signals
  and noise samples

- Computation of RMS noise, peak 25 second noise amplitudes,
  noise spectra, and frequency-wavenumber spectra from noise
  samples

- Computation of signal-to-noise ratios, surface wave magni-
  tudes, and site-to-site signal similarities from signals.

Results from the evaluation are in the process of being analyzed.
Conclusions will be available by mid-October.

3.   SRO Detector

During the past quarter we have been engaged in examining the
design and operation of the SRO short-period automatic detector. During the
course of examining SRO short-period data for evaluation purposes, we have
noted several shortcomings in the design of the detector. First, we noted
that the detector was triggered by the filter response of a spike in the data.
This can be corrected by placing a spike-correction algorithm in the detector
before the data are bandpass filtered. Second, at ANMO and MAIO, a wave-
form of approximately 1.7 Hz from time to time overrides the short-period
seismic data. At the onset of this waveform, the detector declares a detec-
tion. Subsequent detections continue to be declared until this waveform dies
out. On several occasions this waveform lasts for several hours, producing
hundreds of false alarms. These false alarms can be eliminated by changing
the bandpass filter in the detector to a passband of 0.5 to 1.5 Hz. A large
number of false alarms also seem to be caused by the freezing of the long-
term average once a detection has been declared. This is especially notice-
able at SNZO, where, once the detector has been triggered, the detector
stays on for hours.

B.   FUTURE PLANS

We are currently engaged in completing the ILPA and SRO data
analysis and in finishing the evaluation reports.

C.   PROBLEMS

We are at present writing a detailed description of problems
found in the design of the SP detector. This description will be included in
the SRO evaluation report.

An interesting problem currently being studied is the differences
between NORSAR m_b values and NEIS m_b values. In order to make detection

and discrimination capability estimates, it is best to have all m_b values from one event list. In the ILPA evaluation it was necessary to use both NORSAR and NEIS event lists to create the data base. By comparing m_b values for events reported by both lists, we hope to find a way to convert NEIS m_b values to NORSAR m_b values.

SECTION III
DETECTION METHODS

A.   CURRENT STATUS

Research is completed on automatically detecting and timing seismic signals. Preliminary results are:

- Theoretically, phase detection is 6 dB more sensitive than amplitude (envelope) detection. In practice, the realization of this potential 6 dB gain depends on the existence and operating characteristics of a measurable signal phase and amplitude model.

- In SP waveforms, multiple signals arriving within 1-2 seconds after the incident signal prohibit statistical phase detection and timing of the incident signal. Envelope peak detection (requiring that a threshold be exceeded a specified number of times) and stepping back a fraction of a signal cycle (the inverse of the instantaneous frequency) produced timing estimates within 0.3 sec for 80% of the detected signals. It is expected that 50% of the signals can be detected and timed at 3 dB peak-to-peak signal-to-noise ratio (SNR).

- In LP waveforms, a moving-window phase regression algorithm using a priori known signal dispersion yielded signal onset timing within 2 sec accuracy down to 4 dB SNR. Below this level, signals could be detected possibly down to 0 dB SNR, but could not consistently be timed with less than 50 seconds error.

In the last quarterly report, it was reported that a new adaptive beamforming (ABF) algorithm was developed and its performance was evaluated with a number of low magnitude events in central Eurasia. The general processing gain was about 4.5-6.5 dB. This was equivalent to what one would get by beamforming, if the array size was tripled. The continued progress in this quarter included (a) completion of ABF processor's response pattern measurement, and (b) a simulation study with various levels of input single channel signal-to-noise ratio.

The measured ABF response pattern in general followed the beamsteer mainlobe which had a 60° beamwidth at -6 dB level. The simulation results obtained by burying the signal in noise suggested an ABF threshold reduction of 6 dB from the beamsteer processor level, which was in agreement with the processing gain reported in the last quarterly report.

Under the Detection Association Processor (DAP) task, depth dependence was put into the automatic event location algorithm. Functions were constructed for more accurately generating the travel time and ray parameter. The earth model to be used to generate simulated event detection bulletins was modified with the above improved functions to more accurately reflect the effect of depth on the simulated observations of seismic waves.

During this quarter, work was initiated to improve estimates of network capability. In addition to seismic noise, account is taken of the magnitude bias associated with each type of tectonic province. Also, an empirical investigation was made of the apparent relationship between seismic noise and tectonic magnitude bias. The results of this investigation, which is still in progress, will be used to try to improve the accuracy of predictions of the capability of hypothetical networks, and to assess the extent to which the magnitude bias associated with tectonic province influences measurements of network magnitude.

B.   FUTURE PLANS

Reports are in progress on all of the Detection Method studies.
The investigation of magnitude bias should be completed this month.

SECTION IV
EXTRACTION OF EVENT WAVEFORMS

A.   CURRENT STATUS

An adaptive filter was developed to extract long-period body-wave phases based on their expected polarization. Attempts made to modify the polarization criteria used for detecting shear waves were not successful. For detecting P waves, a threshold reduction of up to one magnitude might be possible. Tests were performed using the Wiener filter cascaded with the three component adaptive filter (TCA) to extract weak surface waves. Final results indicate that a reduction of threshold of up to 0.9 magnitude might be possible, compared to bandpass filtering.

B.   FUTURE PLANS

The interpretation of data is continuing and report preparation is in progress.

C.   PROBLEMS

The polarization methods are characterized by an ambiguity caused by a large number of apparent detections in noise. By only accepting detections of signals much larger than the ambiguous ones, the variance of the signal magnitudes were observed to be in excess of 0.8. Estimates of gains, therefore, are not very precise on this basis. One possible preliminary interpretation of the process is that the method is very effective for detecting weak events, but that the magnitude of such detections cannot be accurately measured.

SECTION V
INTERACTIVE SEISMIC PROCESSING

A. CURRENT STATUS

During the past quarter, work was completed on the implementation of the Extended Interactive Seismic Processing System (ISPSE) on the PDP-15/50 for supporting standard seismic processing tasks. The effort was based on the extension of the existing Interactive Seismic Processing System (ISPS) to support two additional features: (1) a programmable mode of operation permitting the definition of standard seismic processing tasks from existing processing modules; and (2) an Interactive Seismic Programming Language (ISPL) with which the user can create his own modules on-line. ILPS provides many features including generous arithmetic and logical capabilities, automatic x-y plotting on the CRT, display of tabular information on the CRT, automatic I/O to named direct access disk files, and special numerical operators to accomplish multivariate discrimination analysis.

In summation, work accomplished on this task during the past year enabled ISPSE to provide a more complete seismic processing environment.

The coarse status reformat of the KSRS reformat program was installed and tested. Over the past several weeks it has not been possible to transmit coarse status data due to the unavailability of Datacomputer time. Presently, work is concentrated mainly on documentation of the software.

B.   FUTURE PLANS

At the present time, a technical report intended as a comprehensive user manual for ISPSE is being written. The report is scheduled to be completed by the end of the contract period.

Documentation of the KSRS data transfer task is in progress. A demonstration will be presented this month on transmission of reformated SP data to the mass store.

SECTION VI

SOURCE PARAMETERS FROM LONG-PERIOD
SURFACE WAVE DATA

A.   CURRENT STATUS

This quarter, the long-period surface wave source mechanism studies were completed. Extensive data on group velocities, attenuation, and source parameter measurements will soon be released in the report now being edited. Considerable scatter was observed in the strike direction of the eastern Kazakh tectonic strain release solutions; the dilatational moments ranged from 1.0 to 1.5 of the apparent earthquake moment; the mechanism was consistently dip-slip. For the Nevada Test Site events, the strike was consistently north-south; the dilatational moment, was 1.0 to 1.8 of the apparent earthquake moment; and the mechanism was consistently strike-slip.

B.   FUTURE PLANS

The technical report for these tasks will be completed early this month.