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24 Bit seismic processor for analyzing extra large dynamic range signals for early warnings

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Modified design is presented of existing 24 bit seismic data recorder comprising PC –architecture using PCI bus, ISA bus, and PC 104 bus in a single module to develop a flexible measurement set up. Paper elaborates use of building blocks [Disk on chip (DoC), GPS based timing unit, signal-processing module, and efficient software packages] worked out in visual C++ to develop compact sized instrument for quick decision-making with minimum error detection of true events. Paper describes Ethernet connectivity use for data downloading in a laptop without interruption of event data acquisition. Software packages for conversion of recorded data into SUDS and SEISAN formats have been realized and incorporated.

Keywords: 24 Bit seismic processor, Digital seismograph, Early warning, Earthquake, Seismic Alert System

Introduction

Good quality instrumental data, recorded in digital form, is required to understand seismicity of a region, to compute earthquake parameters precisely, to estimate strength of underground nuclear explosion, and for distinguishing between seismic and non-seismic sources and studying their characteristics etc[1]. There is great development of upgradable seismographs[2] (8, 12, 16 and 24 bit architecture). Seismic signal generated due to earthquakes and underground nuclear explosions has a very large dynamic range (160 db) varying from nano volt (micro seisms) to several milli volts (great earthquakes of > 8 magnitudes) and wide bandwidth varying from almost DC (tele-seismic events) to around 50.0 Hz (local earthquakes). No single instrument is generally capable of handling signal of such a large dynamic range and wide bandwidth[3,4]. Seismic recorder based on 16-bit digitizer could not provide desired resolution for entire spectrum of seismic signals emanated from micro to great earthquake. Seismic signal processing becomes very important particularly for source discrimination and in studying source characteristics for understanding geo-seismicity of a region[5]. 16 Bit digitizer based recorder developed at CSIO has limited dynamic range (96 db), limited data storage capacity (16 M bytes), limited pre event duration (48 s) because of its design being around microprocessors/ micro controllers technology, limited data transmission rate (19.2 k bits/s) and accordingly consumes large time to transmit data files from instrument down to laptop because of data transmission through RS-232 serial port. Retrieval of desired event from recorder is also time-consuming because of sequential access to events. Timing module is not GPS based and as such has limited precision[6].

This study presents addition of new features in existing 24-bit seismic processor for analyzing extra large dynamic range signals for early warnings.

Design Methodology

Novelty in Design

Design innovation has been inducted to reduce noise generated by analog preparation module to a level distinctly lower than the least significant bit of A/D converter, which is a 24-bit device in present case. Pre-amplifier has been designed around low current operated devices to provide linearity with respect to amplitude and phase, and quick recovery from overloading etc. Incorporation of 24-bit A/D converter has improved performance in terms of ultra large dynamic range[7,8] (130.0 db or even more). Digital filtering done around a new software package has been incorporated to tackle wide bandwidth of seismic signal. To reduce noise level at the stage interfacing sensor output to analog processor

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board, use of short-shielded cables, high quality connectors and single common ground strategy has been provided. Algorithm realized on PC provided computation of short-term average (STA) and long-term average (LTA) ratio to discriminate between true event and false event[9]. GPS based timing system has been incorporated to keep timing more precise and accurate.

Critical requirement of early warning system is to transmit cautions commands well before actual shaking of the earth starts at vulnerable site or area under seismic surveillance[10]. For this, very quick estimation of earthquake parameters from the data, sent by field stations to central recording station (CRS), is to be done in real time mode[11]. Therefore, instrument design has been improved to send essential part of event data without interruption of ongoing data acquisition and processing being done by it as remote field station. A data file of 'N' second duration (programmable) is generated and is transferred on top priority basis down to CRS[12]. CRS keeps on processing information received from different field stations triggered by true event and process data in real time mode to take decision whether to send tele-commands for immediate actions or not[13].

PC bus architecture based design provided flexibility to reconfigure instrument to meet user's specific technical requirement[14]. It supports PCI-bus, ISA bus, and PC -104 bus. Due to incorporation of PC-104 bus, additional modules/cards can be embedded to the system independent of motherboard. Data acquisition module has in built disk on chip (DoC) that contains system software meant for instrument operation. Data acquisition has facility for field programming and data downloading.

With Ethernet connectivity, instrument has capability to form a local node in regional network (web enabled technology) and facility for remote configuration and data transfer facility. When instrument is a part of local area network with Internet connectivity, seismic data can be exchanged at global level by assigning independent IP address to it. Standard Ethernet connectivity has been used for connectivity between seismic recorder and laptop PC through simple cross Ethernet cable. Assigning IP address of the same class to seismic recorder and laptop computer can download data. The data transfer rate in improved version (10/100 Mbps) and is very reliable. Data format of the system is compatible with international standard software package available for seismic signal analysis (SEISAN) so that instrument can be used globally.

Hardware Design Approach

Hardware design has following essential modules: i) Processor module with Ethernet interface; ii) 24-Bit analog-to-digital converter (ADC) module; iii) DOC module; iv) Signal conditioning card; v) GPS module with antenna; vi) Power supply module; vii) Back plane (mother board of the instrument) card; viii) Instrument health monitoring card; and ix) Hard disk module. Hardware modules have been integrated together to realize an improved version of PC architecture based instrument. Selected processor card is equipped with Intel's embedded Pentium ® MMX CPU (233 MHz) with 128 MB memory and has various interfaces like-PCI IDE interface, Floppy disk drive interface and serial port[15]. Processor card also equipped with a high performance PCI-bus and fast Ethernet interface. Back plane has been used as motherboard in designed system for integrating cards. Backplane has slots to accommodate both ISA & PCI and PC 104 bus based cards.

24 Bit ADC modular card can be programmed for various sampling rates (10.0-1000.0 Hz) for single channel acquisition and up to 200 Hz for multi channel acquisition[16]. Software driver provides an abstraction of a specific hardware and communicates directly with hardware. DOC module is a solid-state disk (memory, 288 MB) and is embedded with processor card through PC – 104 bus. DOC has been used to store embedded software designed for the operation of developed seismic system. Hard disk (80 GB) is used to store true seismic event data in a defined format. GPS card provides location and timing information when true seismic event is detected. In order to make 24-bit upgraded version fully compatible with seismic sensor, a pre-amplifier card for differential input signal has been designed, developed and tested. To verify performance, a calibration facility for seismic sensor is provided as an inbuilt part of instrument. Calibration card has been designed to generate controlled current pulse, which is passed through sensor calibration coil and response to signal is recorded by instrument.

Software Description

Embedded System Software

System software, designed around VC++, takes care for operation of entire instrument as per programmed parameters. Concept of circular memory has been used to accommodate data corresponding to programmable pre event time. Buffer memory capacity depends upon

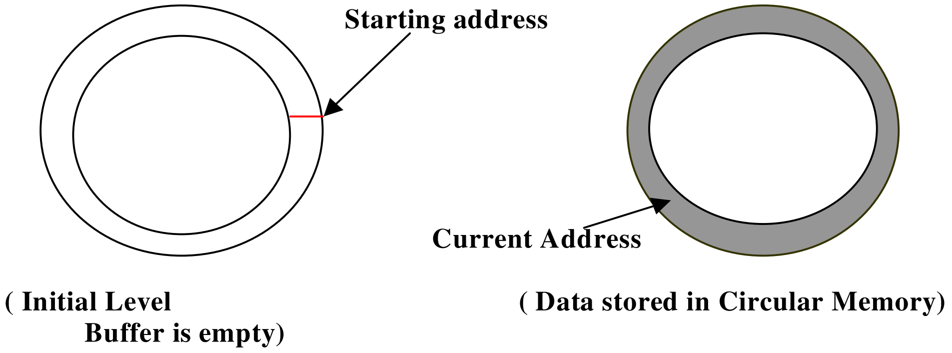


Fig. 1—Design of circular memory

the number of analog input channel, which user wants to read, and also on sampling rate of input signal (Fig. 1).

Size of circular buffer=number of bytes of ADC*sample rate*pre event time. For pre-event time = 20 sec, sample rate = 100 SPS and number of bytes = 24 bit ADC or 3 bytes/sample,

Pre-event = 20 x 100 x 3 bytes = 6000 bytes = 6 Kbytes

For data acquisition, samples will be stored in circular buffer at address stored in circular pointer, which initially contains starting address of circular buffer. After storing data in buffer, address will be incremented by one. Software, on getting buffer, full condition starting address of buffer is initialized as current address for storage. Thus buffer acts as a circular ring. Current address of buffer= base address + incremented address mod size of circular buffer.

Event Detection Methodology

STA and LTA ratio trigger technique have been used for distinguishing between true and false event. Computations of STA and LTA are performed in real time mode (Fig. 2.). In this trigger algorithm, filtered seismic signal processes in two moving time windows (STA and LTA). First, absolute amplitudes of each data sample of incoming signal are computed. Next, average of absolute amplitude in both windows is computed[9]. Initially, STA value for each channel has been computed and then added to compute LTA value. For sampling rate of 50 and STA value of 0.2 sec, number of samples in one STA window for one channel is 0.2*50= 10

STA: X1 = (S1 + S2 + S3 + ————+ S10) / 10

For LTA value of 20 sec, number of samples in one LTA window for one channel is 20*50 = 1000. So number of STAs to be calculated to compute LTA value = 20/0.2 =100.

LTA: (X1 + X2 + X3 + ————+ X100) /100

After calculation of LTA value, fresh STA value is computed. Computed average of current STA and LTA is known as alpha (±) and compared with programmed trigger value for detection of seismic event. ± values for each channel are computed by dividing STA value by LTA value. These calculated ± values would be compared with trigger ratio for each channel for declaring true event. If computed value does not meet triggering criteria then LTA for each channel will be updated as

LTA: LTA - first STA value + current STA value

STA values will be shifted to left to store new STA value in defined memory location. Always new STA value has been computed for new ± value, which is compared with trigger ratio. If event is declared false, LTA value updated. In case, event is declared true, then LTA value is freezed for rest computations and system software captured GPS data from COM port in multi-threading mode. Circular buffer data is freezed for storing pre event data and fresh STA value will be computed for calculation of new ± value, and compared with de-trigger ratio (programmed by user) for declaring end of seismic event and system starts recording for post event period. Finally, event data is stored in HDD with designated file named 'ddmmyyhhmmss' including pre event, timing information, event data and post event data as desired by the user. System re-starts fresh computations.

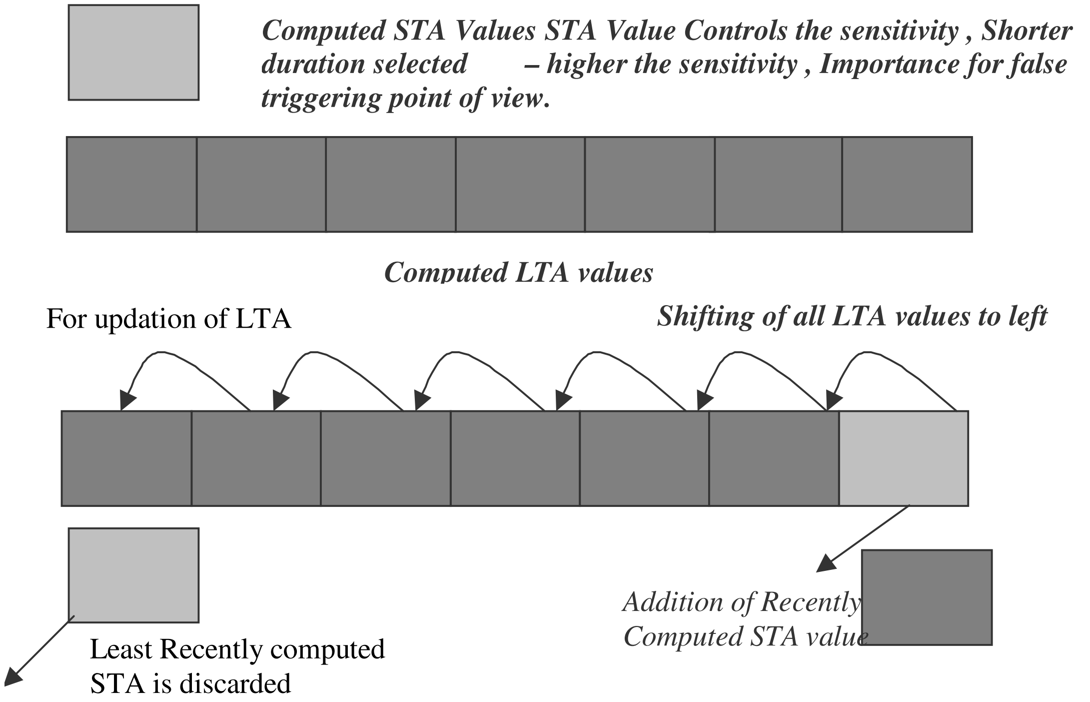


Fig. 2—Computations of STA and LTA

User's Interface Software

User-friendly software in VC++ language has been developed in modular form for entire operation of instrument. One of the software modules is used to program instrument for use by entering pre event period, Post event period, STA period, LTA period, trigger ratio, de-trigger ratio, filter settings and parameters related to field station (longitude, latitude, station number, sensor number, channel number etc). Software also provides commands for start acquisition (on receiving this command system start acquiring data and computes necessary computation as defined in system software for detecting seismic event), stop acquisition (on receiving this command system stop acquiring data and wait for further action) and system restart.

Standard Ethernet connectivity has been used for downloading data. Any laptop can be connected to instrument using standard Ethernet cable. Data can be downloaded both ways by using standard 'Network Neighborhood' available in WINDOWS operating System. Instrument records data in CSIO defined format and recorded data can be analyzed using SEISAN software available in international market. For data analysis, by using SEISAN software, a package has been developed for converting CSIO formatted data into SEISAN format.

Testing and Results

Lab Testing

Instrument was set into operation, but it does not trigger because triggering criteria is not met, since trigger ratio has been set for a value of '3'. During instrument programming, it will trigger only if input signal becomes e≥3 as compared to previous signal value. Constant or slowly varying input signal is treated by instrument as noise irrespective of its level. When signal was increased suddenly > 3 time of its current value at time t1, instrument was found triggered since STA/LTA ratio became > 3, which is desired triggered ratio to declare true event. Then again at time 't2', signal is decreased a level to satisfy de-trigger condition. Instrument was found de triggered and kept recording for post event period. After complete recording, data file for this event was downloaded to laptop PC for evaluation and analysis of recorded data. Data was checked for pre event time, post event time, trigger time (t1) and de-trigger time (t2) (Fig. 3). The data recording was found in agreement with design criteria. Subsequently, instrument was tested by using programmable sine-wave signal as input source. Downloaded data was analyzed on laptop and results were found in compliance with programmed parameters (Fig. 4). Realized instrument is also integrated with seismic sensor. Amplitude of signal is increased by giving manual tapping near sensor. As an when signal amplitude is increased to desire triggered level, system gets triggered until de-trigger criteria satisfies, then finally system records for post event duration. On downloading, recorded data system performance is checked by using SEISAN software (Fig. 5), which is used world wide for seismic data analysis[17].

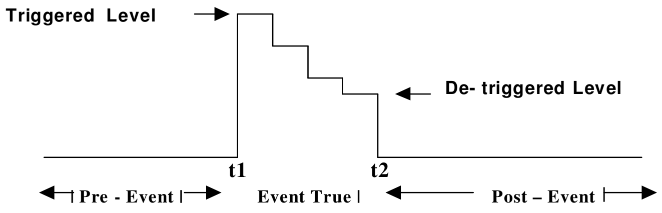
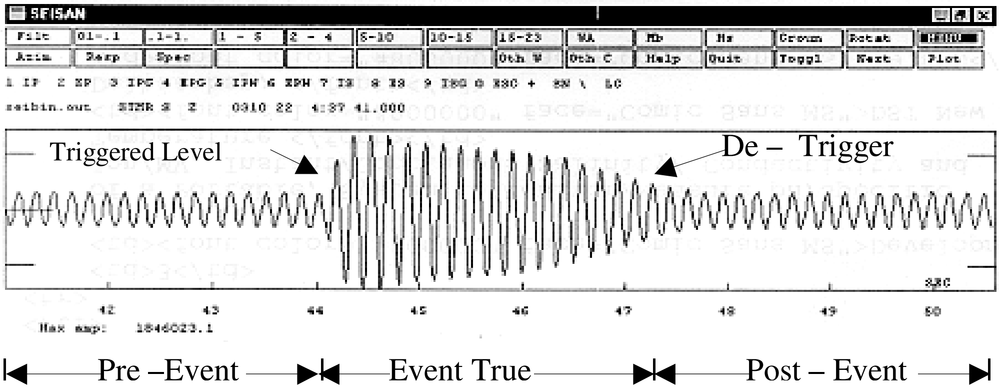


Fig. 3—Recorded DC signal

Field Testing

Field performance of instrument was evaluated at CSIO Seismological Observatory, Chandigarh by comparing its performance with similar kind of 24-bit instrument supplied by M/s Reftek, USA. Both instruments were kept in operation round the clock for very long duration and both recorded true seismic events. Data recorded by CSIO instrument as compared with data recorded by Reftek unit were found satisfactory and in agreement with each other (Fig. 6). Time of P wave arrival, and polarity of first ground motion recorded by both recorders were found similar. Since both recorders were installed in same observatory, therefore, for every earthquake, input ground motion was similar. Data recorded by both units after applying instrument correction was found same. Results of cross-correlation (C-C) between both units were found in agreement. Normalized C-C coefficient at zero lag are > 0.9 in case of each earthquake. C-C coefficient (>0.9) is good



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1 IP  2 EP  3 IPG 4 EPG 5 IPN 6 EPN 7 IS  8 ES  9 ISG 0 ESG +  SN \  LG
seibin.out   SIMR S  Z    0910 22  4:37 41.000
Max amp:   1846023.1
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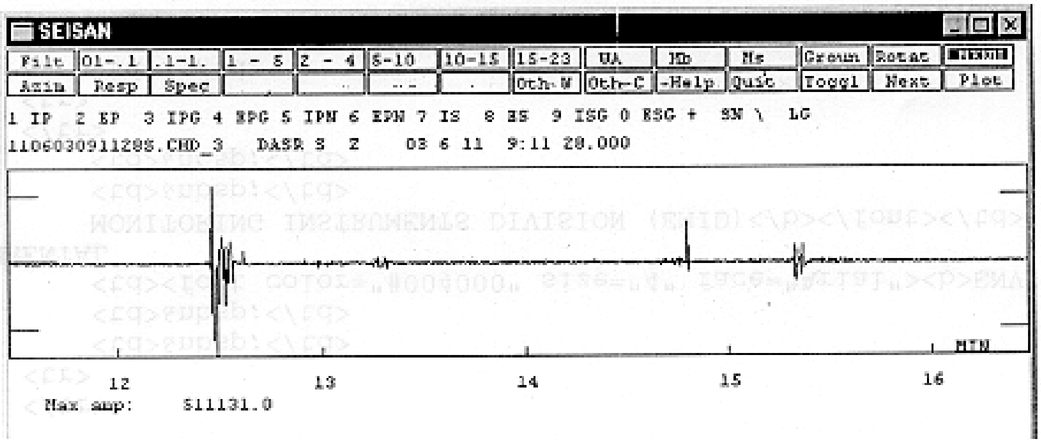
Fig. 4—Recorded sine wave signal



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1 IP  2 EP  3 IPG 4 EPG 5 IPN 6 EPN 7 IS  8 ES  9 ISG 0 ESG +  SN \  LG
1106030911285.CHD_3   DASR S  Z    03 6 11  9:11 28.000
Max amp:    511131.0
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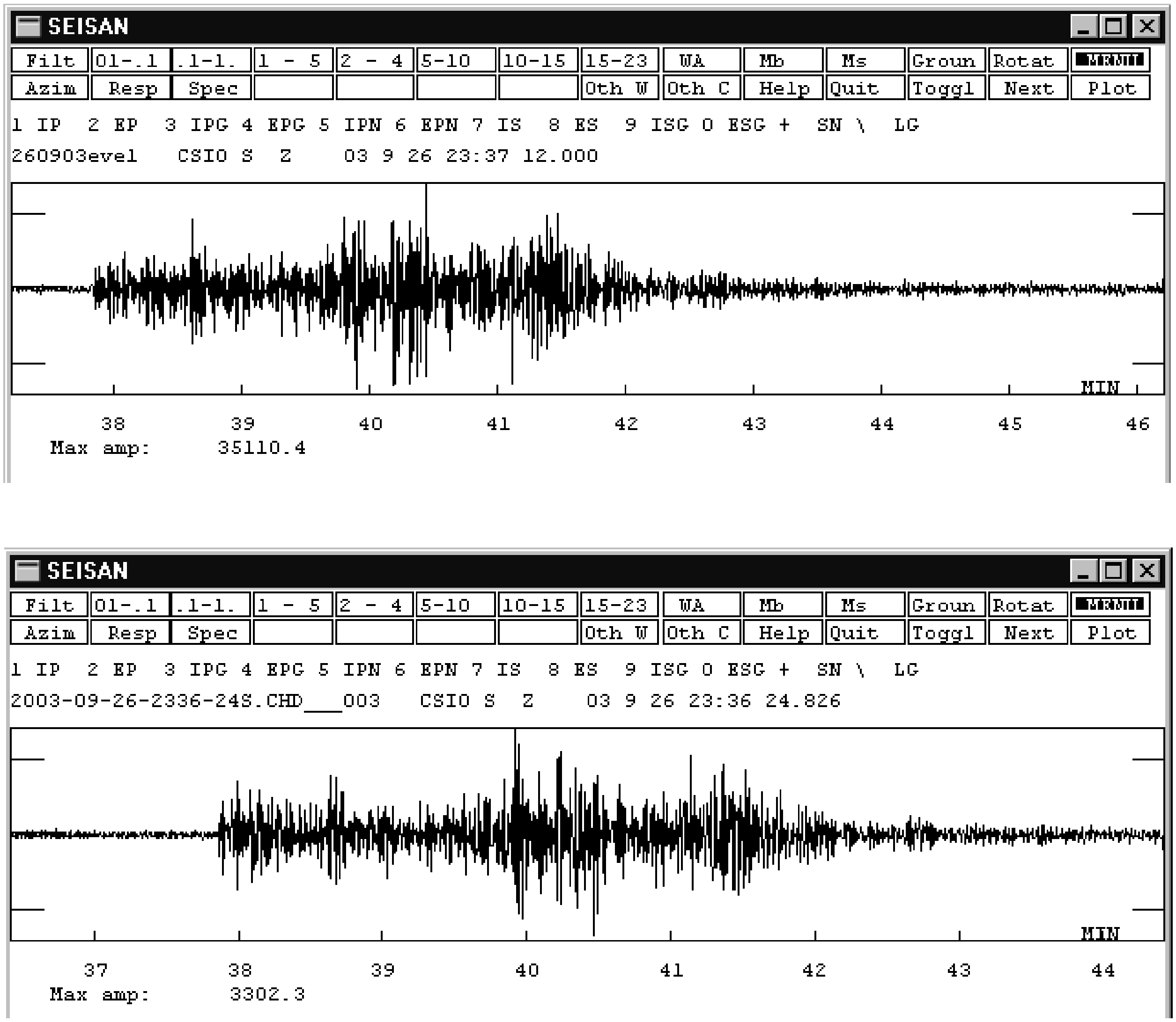
Fig. 5—Signal from sensor tapping



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260903evel    CSIO S  Z    03 9 26 23:37 12.000
Max amp:      35110.4
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2003-09-26-2336-24S.CHD___003    CSIO S  Z    03 9 26 23:36 24.826
Max amp:      3302.3
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Fig. 6—Seismic event recorded by Reftek and CSIO developed instrument

enough to indicate good similarities between two waveform under consideration[18,19].

Conclusions

Performance evaluation confirms validity of design approach. Instrument can be further improved by incorporating methodology for reduction in power consumption, and use of single board/ card to make it more compact and portable. Since instrument was evolved around PC architecture, design approach provides a wide scope to enhance its data analysis capabilities. Instrument can be automated further through embedded intelligence, which can transform it into an entirely new seismic data analysis tool capable of providing earthquake parameters almost instantly on the spot. To develop and incorporate algorithms in present instrument for *in-situ* determination of local earthquake parameters, instrument can be trained around artificial neural network by creating seismic database to perform *in situ* calculations for automatic identification of P wave and S wave, their arrival time, earthquake magnitude, automatic calculation of coda length, epicentral and distance etc.

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