ON RECENT ADVANCES IN STRONG-MOTION DATA ACQUISITION CAPABILITIES

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ABSTRACT

Rapid advances in micro-computer technology have permitted development of general purpose strong-motion data acquisition systems with improved dynamic range, increased frequency bandwidth, increased data storage capacity, and improved computer communications capability. Utilization of low-power microprocessor technology permits greater flexibility in instrument design, instrument application, and field data management capabilities. General system design concepts, example of a General Earthquake Observation System (GEOS), and recorded data sets are discussed.

INTRODUCTION

Rapid advances in technology have initiated a new era in seismic data acquisition. Improved system components permit greater frequency bandwidth and wider dynamic range. Utilization of micro-computers permits software control of various hardware components, efficient and reliable execution of system tasks, increased flexibility in system design, and increased digital processing capabilities. Implementation of these advances into portable field recorders in conjunction with utilization of field deployable mini-computer systems permits acquisition of improved quality strong-motion data.

This paper explores the opportunities in system design permitted by the micro-computer, illustrates implementation of a micro-computer via a General Earthquake Observation System (GEOS), provides examples of strong-motion data collected on the GEOS system, and discusses utilization of field deployable mini-computers in conjunction with micro-computer based data acquisition systems. A review of specifications for several portable digital strong-motion recorders developed within the last decade is presented by Rojahn and Borchedt (Ref. 1).

A GENERAL DESIGN CONFIGURATION FOR MICRO-COMPUTER BASED RECORDING SYSTEMS

Major functions required of a digital seismic data acquisition system include signal conditioning of analog sensor outputs, digital conversion of analog signals, external time reference, event detection, pre-event memory, data storage, operator interface, and data retrieval. Technology permits isolation of each of the various major system functions on corresponding hardware modules with each module under control of a central micro-computer via a general computer bus. This general design configuration is illustrated in figure 1.

The general design configuration illustrated (figure 1) affords considerable flexibility in user application of the recording system and in adaptability of the system to a wide variety of passive and active seismic experiments. Development of general segmented software to control each of the various hardware modules as well as dedicated functions facil-

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itates interchange and replacement of hardware modules for system repair and modification.

Incorporation of a dedicated data bus (figure 1) permits rapid data transfer from pre-event memory to internal or external mass storage medium and promotes efficiency of central CPU. Read capability of internal data storage device and digital to analog module permits playback of data for inspection in analog form. Read capability of data storage device also permits data playback via modem for transmittal via telecommunication.

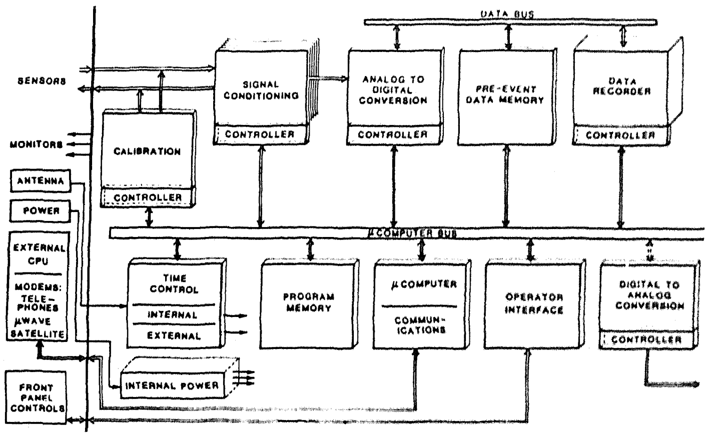

Figure 1. General system configuration for micro-computer based recording system. Configuration isolates major recording system functions on hardware modules under control of central processing unit via general computer bus. Such a configuration facilitates interchange of hardware modules and adaptability of system.

In operation mode, the general system configuration (figure 1) permits the analog signals from a selectable number of sensor channels to be amplified, filtered to prevent aliasing, multiplexed, sampled, temporarily held, and converted to digital signals with accuracy permitted by selected analog to digital converter. CPU control of modules allows for amplifier and filter settings as well as digitization rates to be chosen under software control. Temporary storage of digital data in pre-event memory permits decisions by CPU regarding data transfer via data bus to internal or external mass storage device as well as desired pre-processing prior to recording. System configuration (figure 1) permits augmentation of CPU with external CPU via pre-event memory. CPU control of time reference module permits update of internal time standard at selected intervals with reference time recorded as desired.

System performance specifications and cost are dependent on selection of specific hardware components and associated software developed for the system. A wide range of possibilities exist for various hardware components. For example, options available for the mass data storage device include: tape casssete, bubble memory, solid state memory, tape cartridge or disc with the device selected dependent on system application and price. Similarly, a variety of options exist for other system components.

The general system configuration with selection of various hardware components has been implemented for ocean bottom applications (Prothero, Ref. 3; Moore, Ref. 4) and for land-based applications (Borcherdt and others, Ref. 2). System specifications for the land-based applications are summarized in Table 1.

A MICRO-COMPUTER BASED DATA ACQUISITION SYSTEM (GEOS)

The system designed for land-based applications by the U.S. Geological Survey was developed as a General Earthquake Observation System (GEOS) for use in a wide variety of seismic experiments. The system was designed for use in either an observatory setting or as a portable low-power recorder for deployment in remote locations. Some specified applications for which the system was designed include: near-source strong-motion, structural vibration, crustal refraction, teleseismic, and micro-earthquake studies. A detailed description of the system is given by Borcherdt and others (Ref. 2). The GEOS together with frequently used sets of three component sensors and ferrite WWVB antenna is shown (figure 2). A brief description of general system features is given below.

The signal conditioning module for GEOS is configured with six input channels selectable under software control. Six channels permit utilization of two sets of three-component sensors in order that all seismic signals ranging from seismic background noise to that of the largest quakes can be recorded on scale without change in pre-amplifier gains. Software control of pre-amplifier gains, and filter settings for each channel is especially convenient for adapting the system to a wide variety of different experiments in the field.

The analog to digital conversion module is equipped with a 16 Bit low-power analog to digital converter which affords 96 dB of linear dynamic range. A less expensive 12 Bit analog to digital converter can easily be substituted if desired. Broad system frequency bandwidth is achieved under software control using data bus with maximum throughput rates for the system of 1200 sps. Digitization rates per channel can be chosen as any integral quotient of 1200.

Selection of tape cartridge for an internal mass storage device permits large internal data storage capacity in ANSI standard format. Chosen data format does not restrict the user to specialized tape readers and itates data transfer via tape or RS-232 to computer. Read capability of the cartridge recorder allows recording parameters and system software to be changed automatically and for a system with a modem to transmit data via telecommunication.

Convenient system set-up in the field is achieved using a 32 character LED alphanumeric display. Once the system is turned on, interactive English language commands prompt the operator for proper instrument set-up. Appropriate default parameters defined in the laboratory and loaded via EPROM or tape cartridge permit an essentially automatic system set up in the field.

Low-power consumption using CMOS components permits deployment of the system for up to three days on internal batteries, several months on 12 volt car batteries, or permanently with solar cells or other external power source for maximum reliability should commercial power fail.

A selectable time standard using an internal WWVB receiver, external master clock, or conventional clocks provides capability to synchronize the internal clock as desired under software control with options for recording time-standard updates at selected intervals.

Modular hardware components under control of a central micro-computer using general segmented software facilitiates modifying GEOS for user specified adaptations. Capability to easily interface the system to another CPU via data RAM permits execution of extensive numerical analyses codes in the field.

Figure 2. Illustrations of a General Earthquake Observation System (GEOS) developed with micro-computer control of low-power hardware modules. System designed for use in wide variety of active and passive seismic experiments ranging from strong motion to retraction to teleseismic.

FIELD APPLICATION OF MINI-COMPUTER SYSTEMS

Technology advances have led to compact and more ruggedized mini-computer systems, some of which if properly packaged are appropriate for deployment in the field. Utilization of such systems in conjunction with compatible data acquisition systems permit extensive data processing, analysis, and cataloging at the time of data recovery. Such systems can be especially useful for experiments involving large quantities of data requiring assessment before the experiment can be concluded. Such systems have proved especially useful for seismic refraction studies (Blank and others, Ref. 5) and for strong-motion aftershock studies (E. Cranswick and T. MacDonald, pers. commun.).

Table 1. Specifications for a General Earthquake Observation System (GEOS)

Sensor Inputs and Signal Conditioning

Input Channels: 6 balanced differential inputs, program selectable.
Preamplifier Dynamic Range: greater than 100 dB at 0 dB gain, programmable in 6 dB steps 60 to 0 dB.
Filters: low pass Butterworth, 42 dB per octave; program selectable, 17 Hz, 33 Hz, 50 Hz, and 100 Hz; high pass .1 Hz 6 dB per octave.
Calibration: Internal, automatic with or without sensors.

Analog to Digital Conversion

Resolution: 16 bits (1 part in 65,536).
Stability and Linearity: ± 1 count-no missing codes over full temperature range of -20°C to + 60°C.
Conversion Rate (Total samples per second for all active channels): 1200 samples per second maximum, .29 samples per second minimum; programmable as 1,200/N where N is 1 through 4,096.

Pre-Event Data Memory

Size: 4,096 words, 16 bits per word.
Pre-trigger memory: Five, 512 word blocks minimum at 1,200 samples per second (2.14 seconds), six 512 work blocks at 300 samples per second (10.24 seconds), program selectable.

Program Memory

Executable Memory: 8K 12 Bit word CMOS RAM.
Program Storage: 16K 12 Bit word CMOS PROM.
Alternate Program Storage: Programs may be stored on magnetic tape for loading directly into program RAM.

Internal Mass Data Storage

Cartridge: 3M type DC 300 with up to 450 ft of digital tape at 1600 bpi.
Tape capacity: 3,680 512 word blocks (1.88 million samples) typical for 450 ft. tape, 26 minutes continuous record time at the maximum sample rate.
Tape Speed: 30 ips write or read.

Time Control

External:
WWVB Receiver: Automatic synchronization of internal clock to WWVB under program command.
Master Clock: Synchronization of internal clock with external pulse and corresponding time corrections derivable at selectable times under program command.
Manual: Time entered through keyboard and synchronized manually.
Internal:
Frequency: 3 MHz.
Temperature Stability: $\pm 1 \times 10^{-6}$; - 20°C to + 70° C.
Aging Rate: less than 5×10^{-7} per year.

Operator Interface

Operation Environment: English language commands under software control.
Display: 32 character, alphanumeric display, 18 segment, character height .15 in. LED with optical filters.
Keyboard: Mechanical switch with dust cover and water seal, 20 button keyboard with numeric and function entry.
Status Checks: Time, battery voltage, no. of events, % of tape used, elapsed time since power on.

Communications Interface

I/O Port: RS-232 Compatible, baud rate programmable to standard rates.

Recording Modes

Self triggering:
Near field: Selectable short term average (STA), long term average (LTA), ratio.
Teleseismic: Comparative ratios for two selectable frequency bands.
Pre-set time: record at selectable times and intervals.
Both: operate in both pre-set time and self triggering modes.
Manual: record under keyboard control for start-stop functions.

Power Requirements

Voltage, current: + 24 VDC nominal ± 15%, 40 mA nominal in operating mode with display off, 300 mA nominal with display on, 600 mA with display on and recording.
Internal batteries: ± 24 V, 5 AH Gates type, will operate about 3 days on internal batteries, connector provided for internal battery charging or external battery operation.

Physical and Environmental Requirements

Case Type: Waterproof aluminum case, 20 1/2" long, 9 7/8' wide 13 3/4" high.
Weight: 47 lbs. with internal batteries.
Operating Temperature Range: - 20°C to + 60°C, 15% to 95% rel. humidity.

A mini-computer system developed for field use in conjunction with deployment of the GEOS permits data transfer via cartridge tape to tape or cartridge tape to disc, and interactive video and hard copy display of data. Choice of the mini-computer system and the corresponding operating system for compatibility with larger computer systems operated in a laboratory environment facilitates transfer of appropriate analysis software from lab computers to field computers. Rapid and recent advances in the computer industry regarding compactness of data storage via both cartridge tape and disc as well as miniturization of CPU chips permit significant improvement in field data management capabilities.

DATA EXAMPLES

The portable digital data acquisition systems (GEOS) have been utilized to record near-source strong motion data, microearthquakes, seismic-refraction data, seismic data from down-hole arrays, and some teleseismic data. To date the most extensive application has been to record aftershock sequences in the near field. Several thousand near-source recordings have been obtained following moderate earthquakes near Mammoth Lakes, California (M 5.2), Coalinga, California (M 6.5), and Newcombe, New York (M 5.2) with special studies in New Brunswick, Canada and near Oroville, California. These applications to date have not provided a complete test of all features of the systems in the field; however, they have been useful for examining many features of the system under field conditions and improving field reliability of the systems.

The capability of the system to record the output of a selectable number of sensors up to a maximum number of 6 and to record digital signals for each channel with 16 bit resolution permits the system theoretically to record signals on-scale over a maximum dynamic range of 192 dB. Studies indicate that system noise is confined primarily to the last significant bit, so noise free total system dynamic range is approximately 180 dB. This feature of wide dynamic range has proven especially useful for aftershock studies permitting on-scale recordings of essentially all events in the sequence without change in gain settings.

Examples of data, some of which illustrate dynamic range and signal resolution were collected near Coalinga, California as shown in figures 3 and 4 (C. Mueller and E. Cranswick, pers. commun.) The recordings of the north-south component of ground motion as detected on forced-balanced accelerometers for a magnitude 5.1 aftershock near Coalinga, California is shown in figure 3. Simultaneous recordings of velocity transducers at each of the sites were also obtained. Such a recording obtained at station SUB (see figure 3) for the east-west component of motion is shown as the left trace in figure 4. A recording obtained from the same sensor at station SUB of a much smaller event (M 1.0) which occurred at about the same location as the M 5.1 event is plotted on the right (figure 4) at an amplitude scale expanded by a factor of 100. These examples provide some indication of total system dynamic range and signal resolution.

Selectable digitization rates with a maximum of 1200 sps and selectable number of channels permits considerable flexibility in choice of bandwidth for various experiments. These features of the system have proven useful in studying aftershock sequences in the eastern United

States where attenuation of high frequency signals is much less than for most locations in the western United States. A data example, illustrating system bandwidth (figure 5) was collected in New Brunswick, Canada by E. Cranswick (pers. commun.). The horizontal component of motion was

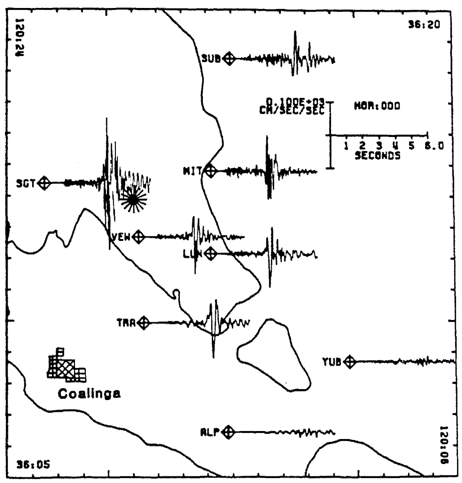

Figure 3. North-south component of acceleration recorded at eight GEOS stations for a magnitude 5.1 aftershock near Coalinga, California. Epicenter for event is indicated.

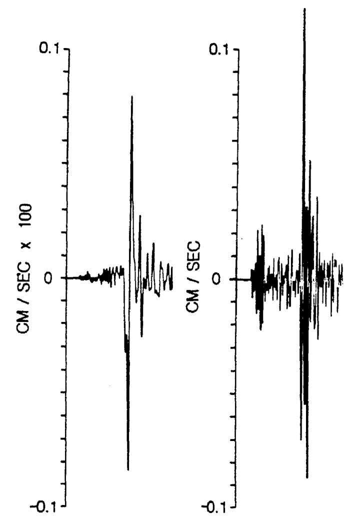

Figure 4. East-west components of velocity from a magnitude 5.1 aftershock (left trace) and a magnitude 1 aftershock (right trace). Comparison of maximum amplitude for left trace with noise level on right trace indicates dynamic range and signal resolution of GEOS.

recorded from a velocity transducer at 1200 sps with no low cut filtering for a small event (M < 1.0) at a distance of about 4 km. The lower trace (figure 5) corresponds to the derived displacement time history. The base line before integration was removed by calculating the geometric mean of the first 512 samples in the time series. Corresponding displacement spectra calculated for frequencies up to the Nyquist frequency (600 Hz) is shown in figure 6. The natural frequency of 2 Hz for the velocity transducer contributes to the spectral fall off for frequencies less than 2 Hz. The spectrum illustrates an extremely broad dynamic range for the recorded signal (> 90 dB) and indicates frequency content of the recorded seismic signal as high as 150-200 Hz. Increments of 6 dB relative signal strength are indicated.