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Mobile Digital Data Acquisition and Recording System for Geoenergy Process Monitoring and Control

Kenneth B. Kimball, Harvey C. Ogden

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Abstract

Three mobile, general purpose data acquisition and recording systems have been built to support geoenergy field experiments. These systems were designed to record and display information from large assortments of sensors used to monitor in-situ combustion recovery or similar experiments. They provide experimenters and operations personnel with easy access to current and past data for evaluation and control of the process, and provide permanent recordings for subsequent detailed analysis. This paper briefly describes the configurations of these systems and their current capabilities.

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Mobile Digital Data Acquisition and Recording System for Geoenergy Process Monitoring and Control

Introduction

Three mobile, general purpose data acquisition and recording systems have been built to support geoenergy field experiments. These systems were designed to provide:

1. Ability to acquire measurement data from a wide variety and large number of sensors.
2. Ability to organize and store data in forms readily accessible to on-site personnel and easily transferable to large scientific computers where more sophisticated processing and analysis may be done.
3. Diagnostic information on and ability to apply mathematical models to physical and chemical mechanisms associated with the experiment for use in analyzing, controlling, and optimizing the process.
4. A simple user interface to allow users with little or no computer experience ready access to data with minimum supervision and without compromising system integrity, and real-time data made available to such users in the form of plots, listings, and CRT monitor displays.
5. Ready adaptability in both hardware and software to different experiment types and configurations.

The systems are housed in 10- x 40-ft trailers which carry Sandia identification numbers B-35, B-49, and B-61. They share the same general system design, but some hardware differences exist between them. Advantage was taken of new equipment models available as new systems were being built, and

some special purpose equipment was obtained for particular experiments. Hardware and software can be transferred between systems for particular experiments. The cutaway drawing of B-61 shown in Figure 1 illustrates a typical trailer layout.

Current hardware and software capabilities of these systems are briefly summarized below. It should be noted that these systems are continually being updated and altered for particular experiments; therefore, at any given time, the precise configuration of a particular trailer may differ somewhat from that described.

Data Acquisition System Hardware

A typical system block diagram is shown in Figure 2. The heart of the system is a MODCOMP general purpose digital computer. It is interfaced to the experiment or process through a variety of analog and digital measurement and control instruments, shown to its left. An assortment of computer peripherals shown on the right provide human interfaces and permanent data recording.

Central Processors

The B-35 and B-49 systems have MODCOMP II central processors with 128K bytes of central memory and 20M bytes of disc memory, and use MAX III, a real-time multiuser software operating system. The B-61 system has a MODCOMP "classic" 7863 CPU

with 512K bytes of central memory and 87M bytes of disc memory, and uses MAX IV, a real-time multiuser software operating system. All three systems have high speed floating point processors, direct memory I/O processors, and 16-bit word length; each is supported by two 9-track tape recorders.

Data Display and Operator Equipment

Three or more operator terminals provide means for user communications with the system. There is at least one printing terminal for logging system activity and one with graphics capability for producing data plots. Limited access by dial-up telephone line from remote terminals is available through an automatic answer MODEM. An electrostatic printer/plotter lists data and programs and makes hard copy data plots. Two video drivers allow us to display data on TV monitors located within a few hundred metres of the trailer. Several monitors may be run in parallel on each video cable.

Sensor and Control Interface Equipment

Terminal strips along one wall of each trailer will accommodate over 1000 pairs of shielded input/output signal wires. Five hundred twelve sets of these terminals are enclosed in isothermal "zone" boxes suitable for use as thermocouple reference junctions. A variety of signal conditioning and conversion equipment is available for processing input/output signals.

A combinatorial multiplexer* (COMUX) is used for scanning thermocouples and other low-level signals. In addition to standard sequential scanning, the COMUX selects various combinations of signal leads, shields, and reference points from multiterminal circuits. The COMUX output is measured with an integrating digital multimeter (IDMM) which will measure dc and ac voltage, current, and resistance. The COMUX and IDMM combination provide capability to make diagnostic measurements and calibration checks along with standard automatic scanning sequences. For example, measurements of sensor loop resistances, noise voltages, and circuit isolation resistances provide valuable diagnostic information for assessing sensor integrity during field experiments.

The COMUX and IDMM may be operated manually during experiment preparation and troubleshooting or under computer control via the IEEE-488 Standard Digital Interface for Programmable Instrumentation (GPIB). Commercial GPIB extenders make it possible to operate these units at distances up to 1000 metres from the computer using two twisted-pair cables.

Three general purpose analog input systems are available to accommodate a wide variety of input signals. Table 1 summarizes their capability and the typical allocation of channels to each trailer.

Channel allocations can be changed to accommodate particular job requirements by simply inserting additional printed circuit cards.

Each channel contains a low-pass filter preceding the multiplexer switches for signal bandwidth limiting. Single- and double-pole filters with cut-off frequencies ranging from 2.8 to 740 Hz, high voltage attenuators and a filter bypass are available or can be purchased to meet particular signal conditioning requirements.

The IEEE-488 GPIB readily interfaces with a large number of commercially available instruments. Each bus can operate up to 15 instruments, such as frequency counters, programmable power supplies, signal generators, gas chromatographs, etc. A pair of GPIB extenders connected with two twisted shielded pair cables allow instruments to be located up to 1000 metres away. Larger separation is possible if MODEMS are used. This provides considerable versatility to meet the wide range of requirements encountered in different experiments.

A general purpose digital input/output interface subsystem (IOIS) provides a wide variety of sensing and control capabilities. It will accommodate any combination of 16 printed circuit cards that provide such functions as contact closures, contact sensing, dc and ac voltage outputs and inputs, alarm sensing, etc. Typically, each card provides 16 signals. A good selection of cards is available in each trailer.

A system to measure earth resistivity has been included in each trailer. Programmable power supplies and/or battery banks are used for injecting excitation currents into the earth. A group switch multiplexes up to 448 sensing electrodes into a set of 64 isolation amplifiers whose outputs are digitized by the wide range solid-state (WRSS) analog input subsystem. Seventy channels of WRSS are available for other uses when earth resistivity experiments are not being conducted.

A current or potential electrode selector (COPES) interchanges excitation and sensing functions among 16 electrodes in any desired combination. In borehole

*K. B. Kimball and C. A. Denney, *COMUX: A Combinatorial Multiplexer for Diagnostic Scanning of Multiterminal Thermocouple and Microvolt Level Circuits*, SAND79-0797.

Figure 1. Cutaway Drawing of the B-61 Trailer Data Acquisition System

Figure 2. Block Diagram, Data Acquisition and Recording System

Table 1 General Purpose Analog Input Systems

	Wide Range Solid-State Subsystem		Wide Range Relay Subsystem	High Level Subsystem
Typical Number of Channels	B-35	96	0*	16
	B-49	80	64	0*
	B-61	96	64	0*
Expandable to		128	128	128
Scan Rate (samples/s)		20,000	30	50,000
Max Common Mode Voltage		± 10 V	± 200 V	± 20 V
Input Range (programmable)		± 5 MV to ± 10 V	± 5 MV to ± 10 V	± 10 V

*Subsystem main frame is not included in system.

arrays, this permits measurements with various effective depths of penetration. One COPEs will service four boreholes containing 16 probes each.

Standard time, as broadcast by the National Bureau of Standards (NBS) over station WWVB, is used to establish a consistent and reliable time base for the system. A WWVB receiver continuously monitors and decodes the NBS signal and accurately outputs the correct time of year to within a few milliseconds. The computer system clock is set to the received time whenever the system is powered up or restarted and is periodically checked while the system is operating. This procedure alleviates the time base problems often encountered in automatic data acquisition systems operating with intermittent or noisy power lines.

A data logger, powered by an uninterruptible power supply, is provided in each trailer to back up critical data channels. This provides continuity of data through periods when the primary system is down because of power or equipment failures or for maintenance and repair. Data logger output is printed on paper tape and recorded on cassette or cartridge magnetic tape. Data logger capacity in each trailer is given in Table 2.

Table 2 Data Logger Capacity

Trailer	Model	No. Channels
B-35	Autodata 8	240
B-49	Fluke 2240A	300
B-61	Fluke 2240A	540

Rack space is available for mounting special purpose signal conditioning or other equipment that may be required for a particular experiment.

Software

The software system for the trailers has been designed to:

- Fully support the hardware
- Be as general and flexible as possible
- Have a variety of user-oriented outputs
- Have a simple user interface

Data can be brought into the system from any of the analog input subsystems, the IOIS, the IEEE-488 instrumentation bus, or the RS-232C communication ports; or it can be hand-entered via a system terminal. The data is stored on disk files to provide fast access for plotting programs, listing programs and other data analysis, and reduction programs. Periodically (usually once a day) the data is copied to magnetic tape to provide backup for the data and to allow it to be conveniently transported to other sites for alternate analysis.

The system provides the user with a variety of tools to observe the progress of the experiment and to analyze the data:

- Time-history plotting of any measurand
- Profile plots
- Contour plots
- Complete data listing capability
- Real-time monitor displays

Figures 3 through 8 include examples of each of these outputs taken from an in-situ oil shale retorting experiment near Rock Springs, Wyoming.

Figure 3. Time-History Plot of Four Temperature Sensors in a Single Instrument Well

Figure 4. Temperature Profile in One Instrument Well at a Single Time

TIME HISTORY DATA LISTING
SCAN TYPE 1
CIRCULAR FILE

866 = TET 0058 C
854 = TET 0068 C
864 = TET 0078 C
852 = TET 0088 C

TIME	866	854	864	852
106.70909	107.627	210.000	80.3964	46.9521
106.75075	108.483	231.088	80.6921	45.7707
106.79242	108.562	250.493	80.0952	44.2497
106.83409	109.109	269.580	79.9398	43.7784
106.87575	109.853	276.805	79.6178	43.4061
106.91742	110.103	281.466	77.7929	43.0502
106.95909	111.051	285.133	75.7931	40.8703
107.00075	112.427	282.907	74.2907	39.7235
107.04242	114.502	274.865	73.7236	38.7898
107.08409	115.298	268.664	73.4297	37.9370
107.12575	115.235	262.642	73.4398	37.5070
107.16742	115.479	257.150	73.3925	37.0163
107.20909	114.876	249.161	73.6131	36.6512
107.25075	116.085	244.282	73.9222	36.6468
107.29242	114.307	242.345	74.0844	36.4434
107.33409	111.068	243.868	74.2180	36.4812
107.37575	110.101	256.689	73.5706	36.1900
107.41742	110.703	265.616	72.4084	35.7673
107.45909	106.147	278.620	71.8608	35.7251
107.50075	105.272	301.863	71.6431	36.1669
107.54242	115.279	370.364	70.5898	35.8305
107.58409	119.664	393.326	69.9787	36.1171
107.62576	123.866	408.935	69.7651	35.6781
107.66742	125.951	423.307	70.1974	35.6764
107.70909	130.254	433.168	70.8791	36.1255
107.75075	129.878	432.569	71.6396	36.5075
107.79242	130.356	443.593	71.5842	36.0822
107.83409	127.065	446.377	72.7753	36.6821
107.87575	110.928	123.888	82.0601	37.9594
107.91742	93.5872	102.955	82.0964	36.8437
107.95909	113.266	109.747	78.9094	36.3231
108.00075	111.934	114.774	79.2983	36.4001
108.04242	113.840	113.816	79.6492	36.4874
108.08409	113.267	113.412	80.3088	36.7173
108.12575	112.147	112.025	80.8117	36.8613
108.16742	111.825	114.252	81.2393	37.1498
108.20909	112.282	116.092	81.6935	38.0029
108.25075	112.265	119.254	81.9417	38.2039
108.29242	112.250	120.647	82.3607	38.6494
108.33410	112.106	128.755	83.0617	39.2087

\$\$

Figure 5. Partial Listing of Temperature Data Plotted in Figure 3

RS-12 MAINBURN		TEMPERATURE WELL TE	TIME=122-12: 1: 4			
TET 001B	XXXXXX	I	I	38.04	0.0	300.0
TET 002B	XXXXXXX	I	I	47.16	0.0	300.0
TET 003B	XXXXXXXXX	I	I	57.97	0.0	300.0
TET 004B	XXXXXXXXXX	I	I	67.00	0.0	300.0
TET 005B	XXXXXXXXXXX	I	I	74.98	0.0	300.0
TET 006B	XXXXXXXXXXXX	I	I	76.48	0.0	300.0
TET 007B	XXXXXXXXXXXXXX	I	I	94.73	0.0	300.0
TET 008B	XXXXXXXXXXXXXX	I	I	86.89	0.0	300.0
TET 009B	XXXXXXXXXXXXX	I	I	72.48	0.0	300.0
TET 010B	XXXXXXXXXX	I	I	55.79	0.0	300.0
TET 011B	XXXXXXX	I	I	43.04	0.0	300.0
TET 012B	XXXXXX	I	I	32.64	0.0	300.0
TET 013B	XXXXX	I	I	24.19	0.0	300.0
TET 014B	XXXX	I	I	17.51	0.0	300.0
TET 015B	XXX	I	I	15.58	0.0	300.0
TET 016B	XX	I	I	14.28	0.0	300.0
	I	I	I	10.0000	0.0	0.0
	I	I	I	10.0000	0.0	0.0
	I	I	I	10.0000	0.0	0.0
	I	I	I	10.0000	0.0	0.0

Figure 6. Histogram of Well Temperatures as Displayed on TV Monitor

Figure 7. Equipotential Contour Plot for Surface Array of Earth Resistivity Probes

Figure 8- Time-History Plot of Some Production Well Gas Components

Measurand Definition File

In order to be as general and as flexible as possible, the system is "table driven"; that is, all the parameters that define a particular experiment are stored in a disk file called the "Measurand Definition File." This file defines all the measurements to be taken, and provides the acquisition program with the information it needs to take the data and all other programs with the information they need to interpret the data. This approach eliminates the need for reprogramming for every new experiment. It is the responsibility of the experimenters to provide the information necessary to create the Measurand Definition File.

Scan Types

The total set of measurands can be subdivided into 32 subsets called scan types. Each scan type is assigned its own scanning interval and has its data stored in its own disk file. Measurands may be added to or deleted from a scan type and the scanning interval changed as desired throughout the course of an experiment. This provides the flexibility required to adjust sampling rates to be consistent with process

activity in regions near particular sensor groups while minimizing the volume of data to be stored. It also allows us to run multiple experiments concurrently and keep their data separated.

Menu

To make it easier for the users to access the system, it has been designed so that all system resources are accessed through a master "menu" program. That is, the resources of the system are displayed on a terminal in very general categories. The user selects a category he is interested in and another menu is displayed with specific items in this category. The user then selects one of these items and a particular system program is activated which will prompt the user for the information it needs to produce the desired output. At each step of this process the computer instructs the user about what he needs to enter next. This allows users with little or no computer experience to access the data with minimum supervision and in such a way that the integrity of the system is protected.

Event Log

An event log is maintained in a disk file to document all activities pertinent to the experiment. Actions initiated on the computer terminals are automatically entered in the event log; e.g., changing measurands in a scan type or changing scan frequency. Other activities are manually entered by the operators; e.g., plumbing alterations or equipment modifications.

The MODCOMP computers, together with the operating systems under which all this software is run, provide considerable room for future expansion. Because of the flexibility of the "table-driven" approach, new applications can be added with a minimum of difficulty.

Field Support Requirements and Equipment

Power

Three-phase, 208-V, wye-connected power is required to operate the trailers. Utility power drain is typically 25 to 30 kVA for operating heaters, air conditioners, lighting, etc. Instrument power drain for operating the data acquisition and computer equipment is typically 3 to 5 kVA. The trailers are wired to accommodate backup and separate instrument power sources when these are required to improve reliability and quality. A one-line diagram of the power input circuitry is shown in Figure 9.

Sensors in the automatic transfer switch monitor the voltage of the primary and secondary power sources. If an out-of-limits condition occurs in the primary source, the switch will transfer to the secondary source only if that secondary source is within limits. Switchback to the primary source can be done manually or automatically after the primary has been in-limits for a preset period of time. A diesel generator with automatic start capability may be used as the secondary power source. The transfer switch controller provides the necessary control signals to start the generator within 10 s after a primary power failure. The automatic power fail restart feature of the computer system will prevent any loss of data and will reinitiate any scans that were in process when a power interruption occurred.

An input connector and manual switch are provided to accommodate an optional independent power source for instrument power. All instrument power, regardless of the source, is passed through ac power line conditioners to remove disturbances and noise. A transient protector following the transfer switch protects against fast high-energy surges such as lightning strikes.

Provisions have been included for grounding the trailer shell and power line neutral at a single point such as a wellhead. Appropriate warning lights are included for situations where the trailer shell might be at a potential different from local ground.

Figure 9. One-Line Diagram of ac Power Input Circuits

Temperature Control

Two 5-ton refrigeration units and electric heaters provide temperature control for the electronic gear. Ducts in the ceiling and floor provide closed-loop circulation to the equipment racks. Each rack is equipped with a fan and adjustable louvers for regulating air flow. Rack temperature sensors are wired to local readouts for operator convenience and to the data acquisition system so they can be included in the data base for diagnostic purposes.

Test Equipment, Tools, and Equipment Maintenance

A reasonable complement of tools, test and calibration equipment, and spare parts is carried in each trailer. This allows field operations personnel to set up and maintain the experiment, and to perform minor repairs and maintenance on trailer equipment. Specialized field service technicians are called in or equipment is returned to the factory for major repairs, depending upon the urgency of the situation and the availability of backup equipment. We keep a standard full-service maintenance and repair contract with MODCOMP to service the computer equipment. This provides regular periodic preventive maintenance by qualified MODCOMP servicemen and 24-h response to remedial service calls.

Conclusions

The three mobile data acquisition systems described have been used to monitor several types of geoenery field experiments. These systems have proven very beneficial in cataloging and recording large quantities of data and making them easily accessible for prompt on-site evaluation and control of experimental processes. System hardware and software are flexible enough to easily adapt to a wide variety of sensor types and experiment configurations, and provide room for future expansion. Software is transportable among the three systems; so features added for each new application benefit all three systems. Therefore, the capabilities of these systems and the convenience of using them are constantly improving.

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