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A UNIX Workstation Monitoring System for Coal-Bump Research

By J. P. Coughlin and P. E. Wilson

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot
ft•lb	foot pound
h	hour
Hz	hertz
kHz	kilohertz
km	kilometer
km/s	kilometer per second
m	meter
min	minute
ms	millisecond
s	second
V	volt

A UNIX WORKSTATION MONITORING SYSTEM FOR COAL-BUMP RESEARCH

By J. P. Coughlin[1] and P. E. Wilson[2]

ABSTRACT

The U.S. Bureau of Mines has developed a monitoring system that acquires and analyzes data for use in determining the conditions that may precede mountain bumps in coal mines. Based on a UNIX workstation linked to an array of geophones in a working longwall operation, the system captures complete waveforms of microseismic events and simultaneously obtains continuous samples of the voltage levels of each geophone. Event rates and locations are calculated and displayed in real time on the UNIX workstation, which is situated in an underground instrumentation room. These results also are transmitted from the workstation to a display computer near the longwall face. The system runs continuously and has the capability to acquire, analyze, display, and archive microseismic (transient) data and single point data, such as closure and pressure changes, simultaneously.

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INTRODUCTION

Bumps are sudden violent failures of mine rock that can injure mine personnel and damage mine structures and mining equipment. In a 3-week time period of exceptionally high bump activity, the monitoring system described in this report detected 2 very large bumps, 10 bumps of intermediate or small size, and 21,000 microseismic events (small-scale rock fractures). The 2 large bumps caused extensive damage while the 10 smaller bumps caused a lesser degree of damage.

The goal of the U.S. Bureau of Mines research described in this report is to develop empirical techniques for forecasting mountain bumps. Much of the current work toward this goal is based on the acquisition and analysis of microseismic data. Laboratory testing and field studies support the idea that patterns of microseismicity are related to the onset of failure in materials. Some of the earliest work in microseismics indicated that peak event rates may be precursors to the failure of materials (*3*).[3] Many other laboratory studies, among them Scholz (*8*) and Reymond (*5*) have indicated the same relation. However, a coal bump in a longwall operation is different from the failure of a relatively uniform test specimen under controlled conditions. The geological environment of a coal mine consists of several bedding planes of differing materials, each plane having its own heterogeneous characteristics. These geological and physical complexities may preclude the use of rate anomalies alone in bump forecasting, but other parameters that may be related to bumps are being investigated. Rowell (*7*), analyzing data obtained with the system described here, reports that more than a month ahead of time the spatial distribution of microseismic events outlined the area where a very large bump was to occur (fig. 1). Some field studies on the energy distribution of microseismic events have found a probabilistic relation between this parameter and the occurrence of large, damaging bumps. Revalor (*4*) determined that a low event rate with an energy distribution concentrating more than 35% of the energy in high-energy events indicated that the

[3]Italicized numbers in parentheses refer to items in the list of references preceding the appendixes.

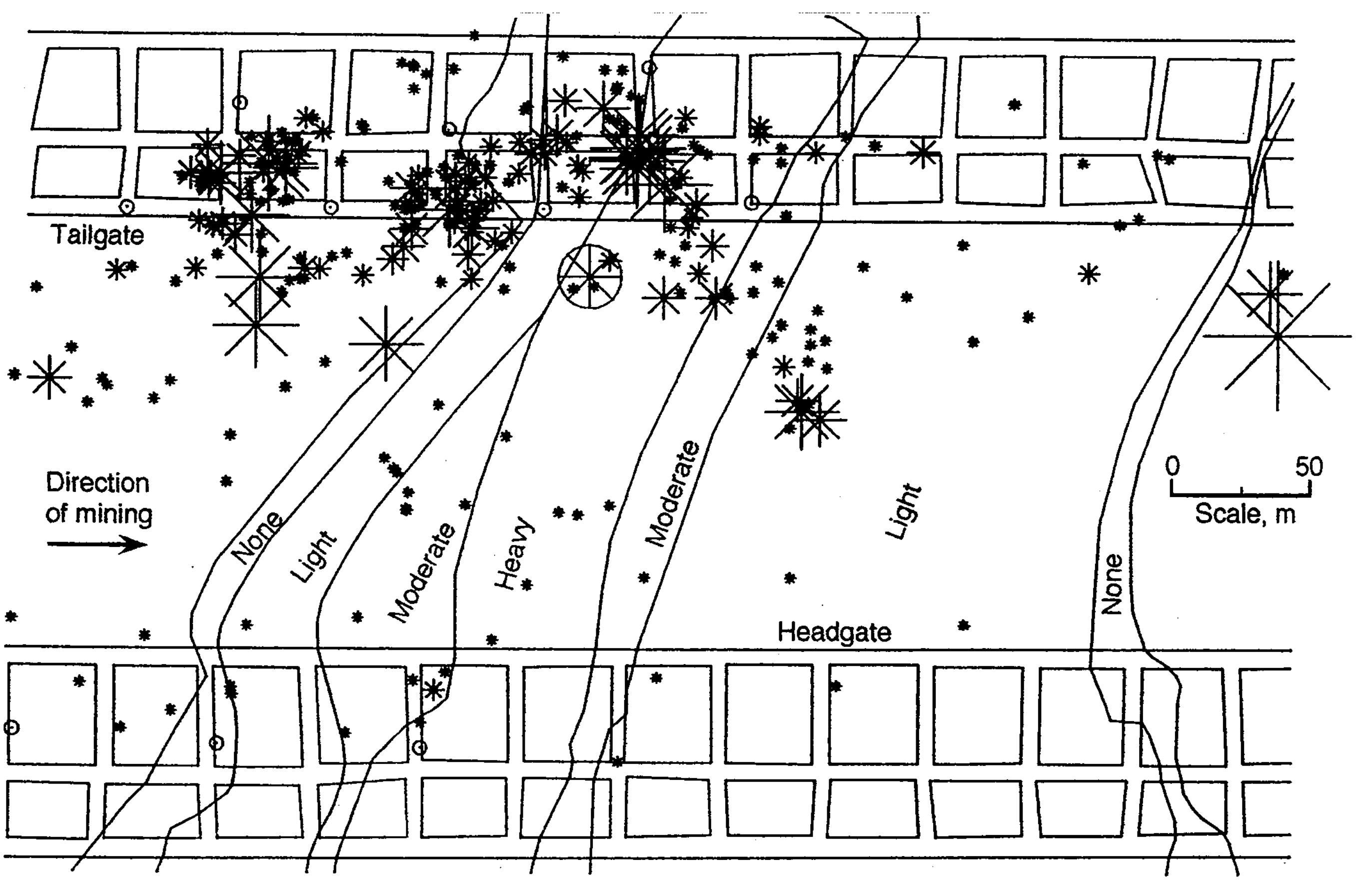

Figure 1.—Microseismic activity (September 30 to October 12, 1989) ahead of the face. Asterisks denote event locations and are logarithmically proportional to event energy. Longwall face was 800 m to the left of the figure edge. The wagon wheel symbol marks the location of a mountain bump that occurred 1 month after the depicted events. At the time of the bump, the face was 20 m to the left of the bump location.

longwall face was approaching a dangerous area. Lasocki (*2*) showed that for several observation periods high-energy events had a 70% to 80% tendency to occur when the calculated probability of these events was increasing. It is emphasized here that although these results are promising, it is nonetheless true that the longwall can be in a dangerous area without any excessive concentration of energy in the high-energy events, and that a coal bump can occur even when the calculated probability is low.

Several digital microseismic monitoring systems have been developed by the USBM as part of a research effort to reduce the hazard of bumps and rock bursts. One such system designed for monitoring hard-rock mines is described in reference 1. The present report describes the implementation of a monitoring system designed specifically for use in coal-bump research. An overall description of the monitoring system is given, followed by examples of system data and a description of how the system operates.

MICROSEISMIC MONITORING SYSTEM

The USBM monitoring system presently operates in an underground coal mine in eastern Kentucky. Situated in a fresh-air entry 500 ft from the stop line of the nearest coal panels, an instrumentation room (fig. 2) is connected through several thousand feet of signal cable to an array of geophones (fig. 3) positioned around the currently active longwall. Power for preamplifiers, which compensate for signal losses in the cables, is provided from within the instrumentation room by a USBM-designed power supply with special circuit-breaker features (*5*). With this unit as a power supply, the geophones, preamplifiers, and cables are permissible for use in underground coal mines under Mine Safety and Health Administration permit EP-715-0.

The main part of the USBM monitoring system is a Concurrent Computer Corp. UNIX workstation[4] with an integrated data acquisition system and the capability of simultaneously acquiring data and running multiple analysis and display routines.

Operating under the control of USBM-developed software, the UNIX workstation acquires data with two sampling systems. The primary system acquires full waveform data at the sampling rate (5 kHz per channel) of the data acquisition hardware. A secondary system, operating at the much-reduced rate of 80 Hz, samples the data provided by the acquisition hardware and obtains quasi-random continuous samples of the voltage output of each system geophone. All data are archived periodically on magnetic tape for future detailed analysis while preliminary analysis on-site derives event locations and rates from the full waveform data. Along with the continuously sampled data, these locations and rates are displayed in real time in the underground research station (fig. 4).

A multitasking microcomputer installed in fresh-air flow near the longwall face (fig. 5) serves as a remote display for the UNIX workstation. Several thousand feet of cable and two modems transmit event locations and rates from the UNIX workstation to this computer, which displays these results in a 2-day time window that begins at midnight 24 h prior to the current day. The event location display is updated as each event occurs; the rate display is updated at least every 15 min.

[4]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

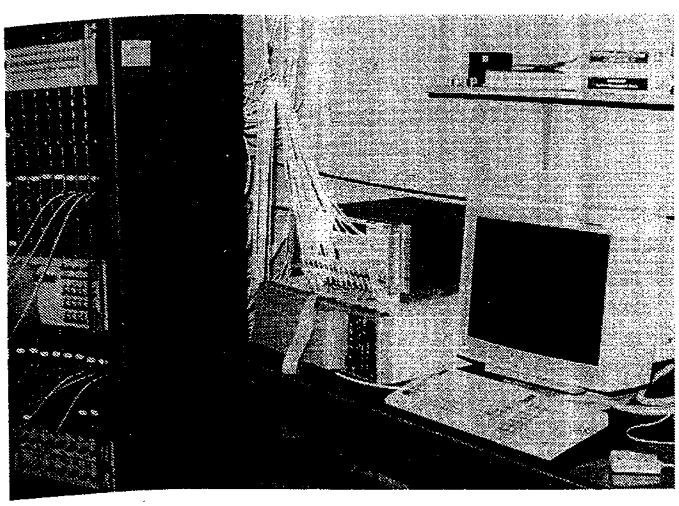

Figure 2.—Instrumentation room. From left to right are shown the amplifier and power supply rack, the event detection hardware, and the UNIX workstation.

Figure 3.—Geophone installation.

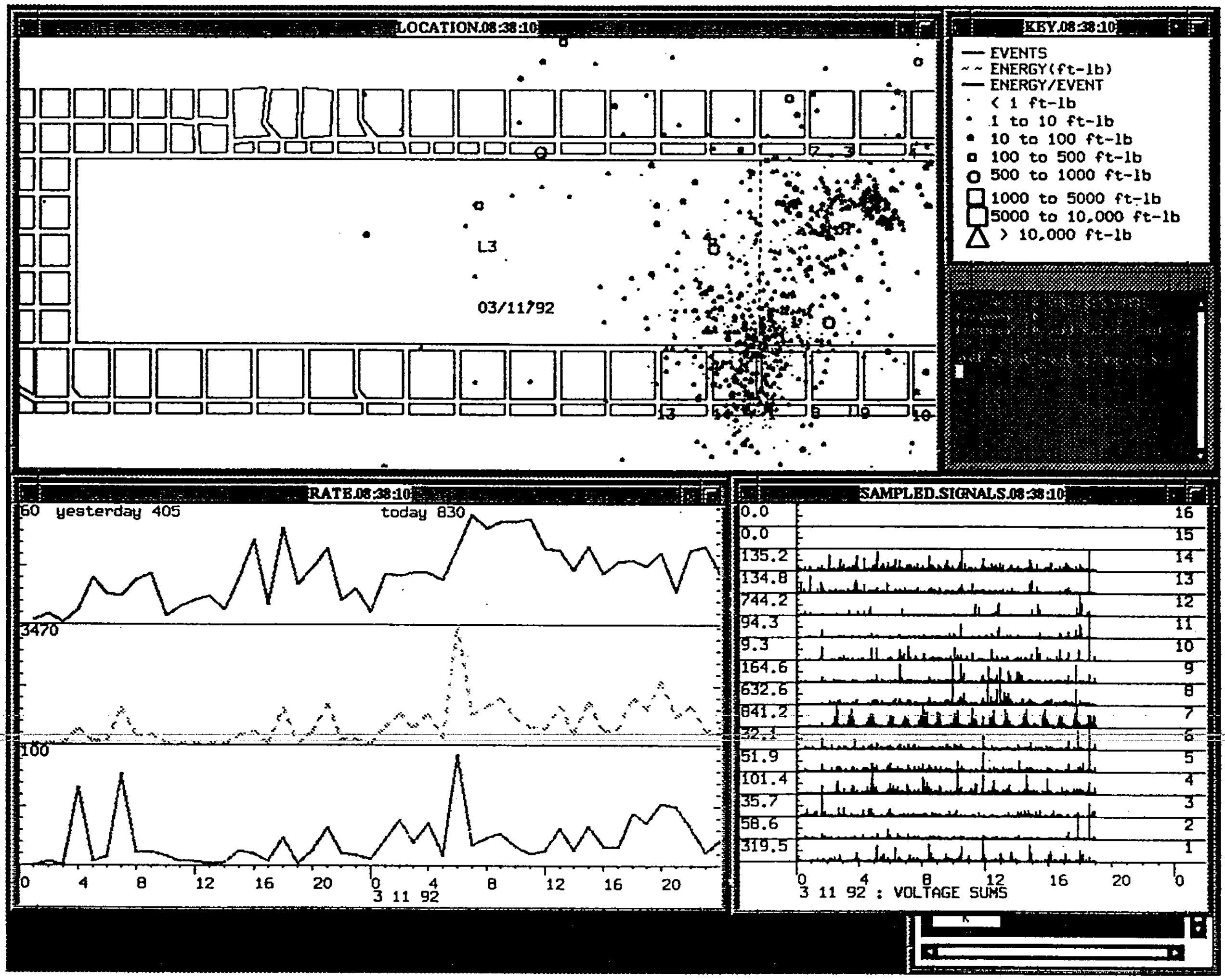

Figure 4.—Actual monitoring system display. Locations are updated each time an event is located. Sampled signals are updated every minute and the rate plot is updated at least every 15 min.

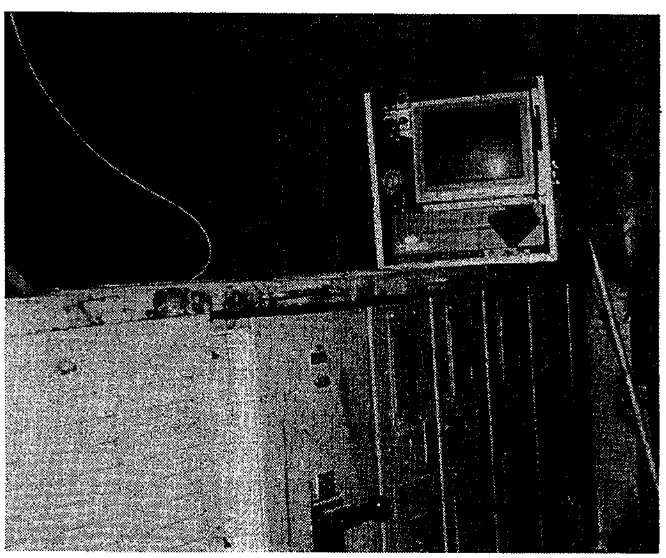

Figure 5.—Near-face monitor.

The basic types of data that the system acquires are transient event data (high sampling rate) and continuous data (reduced sampling rate).

TRANSIENT EVENT DATA

Figure 6 is a multichannel display of the waveforms associated with a microseismic event detected by the USBM monitoring system at the research site. When a microfracture occurs in mine rock, an elastic wave is generated. This elastic wave, having a duration that may range from less than 20 ms to more than 100 ms, propagates through the mine rock at a velocity (average 4 km/s) that is characteristic of the point-to-point geology and stress state within the mine rock. Geophones deployed in an array around the zone of microseismic activity convert the incident wave into a voltage signal. In the USBM monitoring system, this voltage signal is sampled continuously by the computer-based data acquisition system. When certain

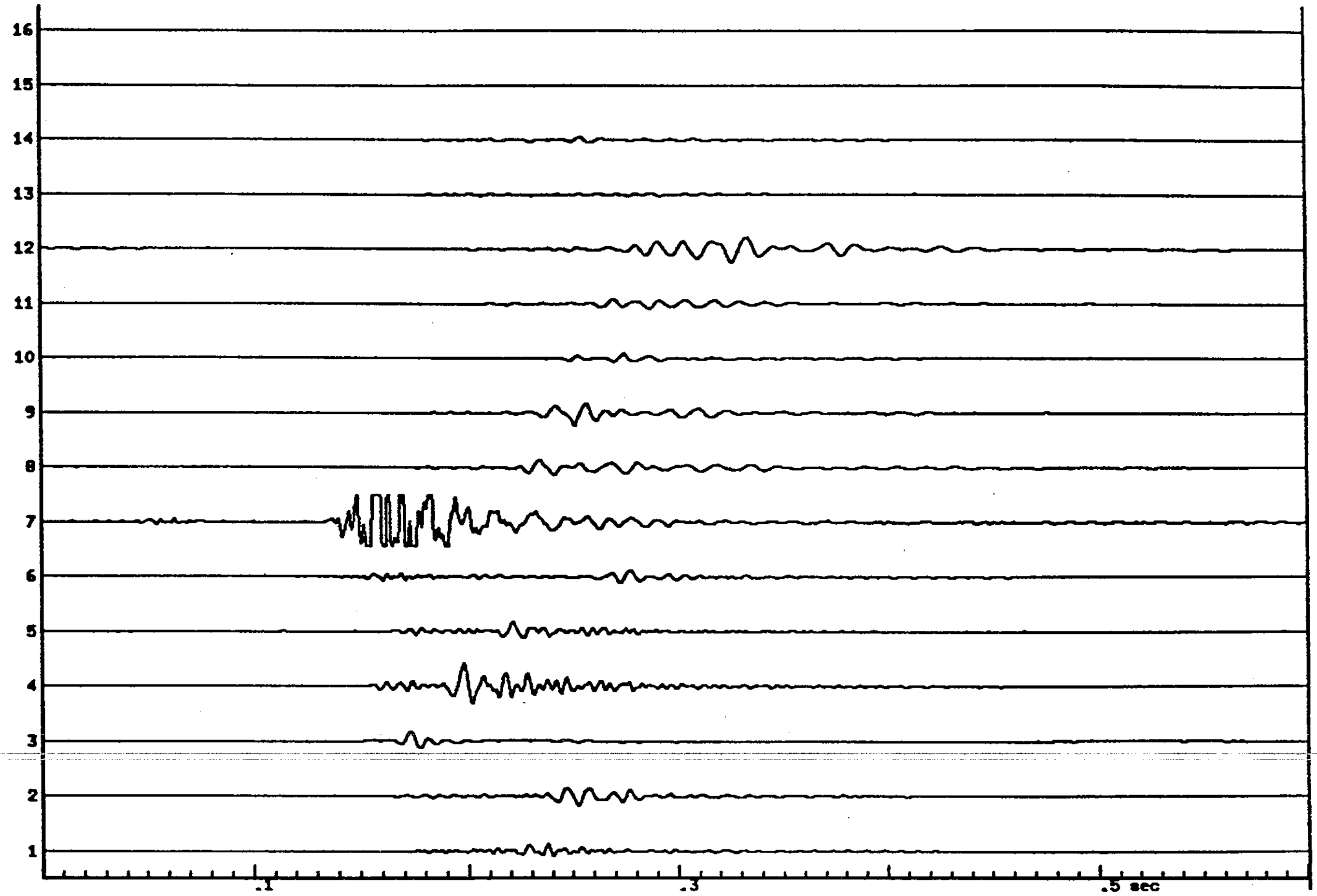

Figure 6.—Actual multichannel waveform display (vertical axis is −10 V to +10 V for each channel).

hardware-determined conditions are met, the system recognizes that a microseismic event has occurred and subsequently stores the set of voltage signals spanning the duration of the event. This type of data acquisition, providing limited-duration data such as that depicted in figure 6, is known as "transient capture."

CONTINUOUS DATA

Besides acquiring transient waveform data, the monitoring system records continuous samples of acoustic emissions in the vicinity of each system geophone. From the output of each geophone, three parameters that may be related to local activity are obtained, a count of the number of times the voltage exceeds a given threshold, the sum of the absolute value of these voltages, and the maximum value among the voltages. These parameters are based on geophone voltages sampled at the rate of 80/s and compiled over a time window of 1 min. When the 1-min time window ends, the corresponding parameters are posted as an update to a display covering a midnight-to-midnight time period.

Within the limits described in appendix A, the continuous data acquisition system may provide a quantitative measure of the activity local to each geophone, and does provide a measure of longwall advance. Thus, each channel in figure 7 shows, to some degree, a periodic modulation caused by the action of the shearer in sweeping back and forth across the face. With the number of cycles equal to the number of shearer passes and a known average cut size on each pass, the longwall advance rate can be obtained. This measurement is useful in normalizing the detected event rate to the rate of longwall advance. One planned use of the continuous data acquisition system is to obtain comparisons between microseismic activity and slowly varying mine-environment parameters, such as convergence or pressure change. Since all data will be acquired under the same acquisition system, synchronization of measurements is possible down to the time between samples in the continuous sampling system (0.0125 s in the current system). Two conceivable applications for this are in destressing operations and in the long-term monitoring of mine structures such as yield pillars.

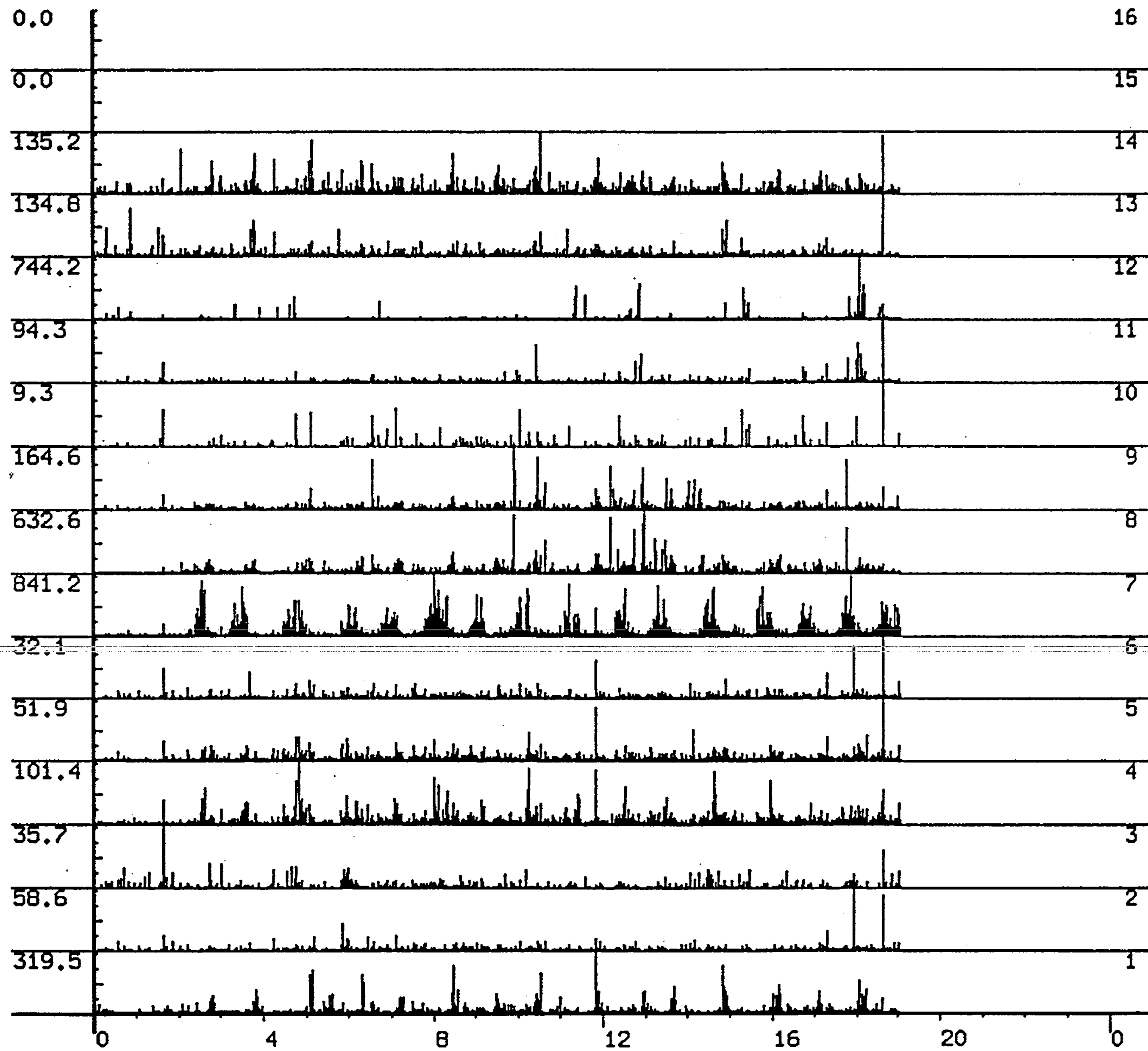

Figure 7.—Actual continuously acquired signal data display. The vertical axis is the sum of the voltages in each channel in 1-min time periods. Horizontal axis is time in hours. Shearer passes cause the periodic rise and fall of signal that may be seen on most channels.

SYSTEM OPERATION

Figure 8 is a block diagram of the USBM monitoring system. As the figure shows, elastic waves incidents at each geophone are converted into voltage signals that are amplified and then transmitted via several thousand feet of cable to the acquisition system in the instrumentation room. After frequencies outside the range of 25 to 800 Hz are filtered out, the signals are amplified a second time so as to be in the proper range for the digitizing electronics. Subsequent to this, the signals are transmitted in parallel to the UNIX workstation and an external event detection instrument. On the workstation, a software-controlled data acquisition system continuously digitizes each voltage signal, storing the numerical results in a set of memory buffers organized as a ring. The event detection instrument provides the workstation with a signal indicating when the current set of buffers contains a waveform

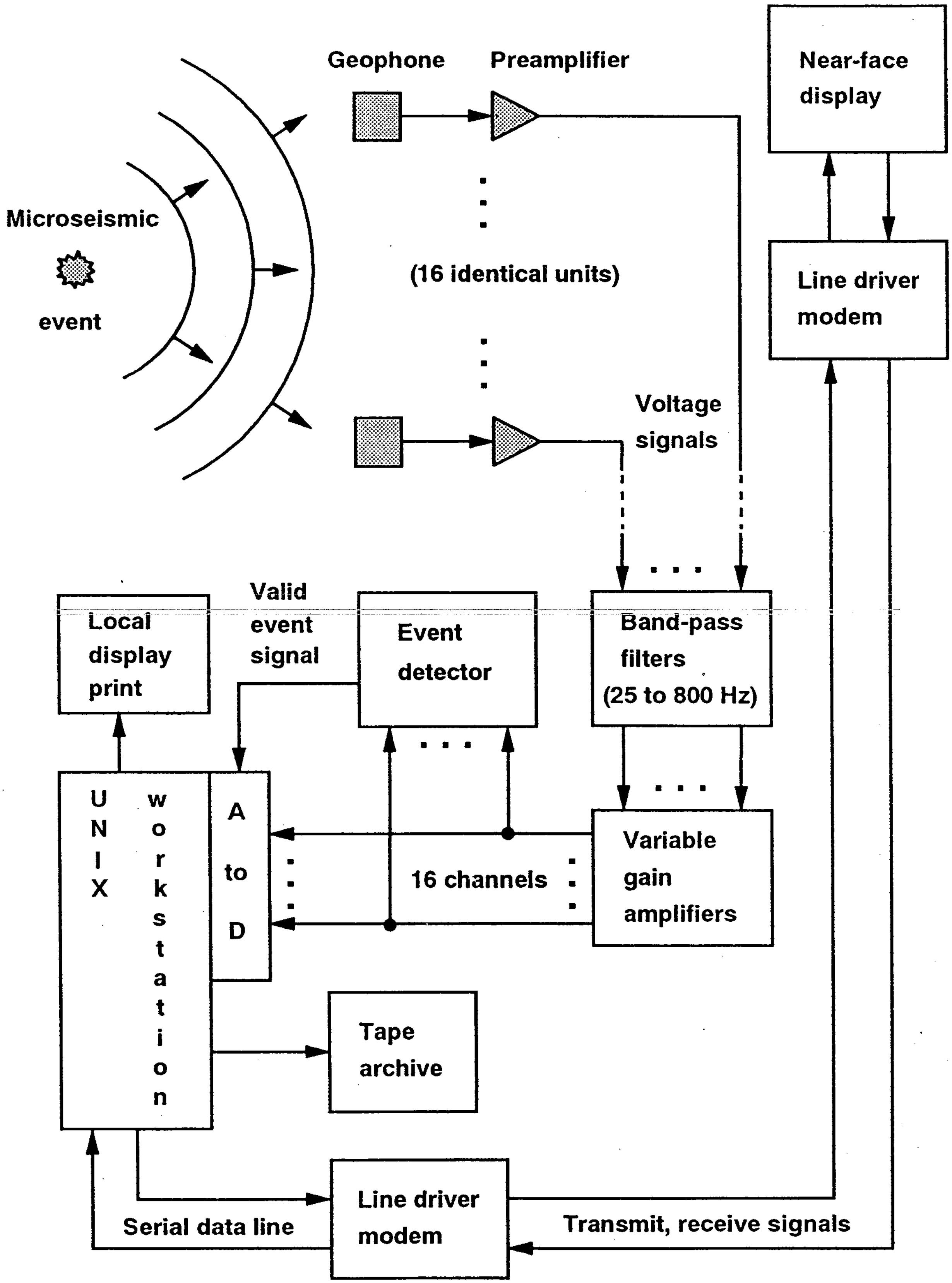

Figure 8.—Microseismic monitoring system.

associated with a microseismic event. If no signal is supplied, the workstation software discards the oldest portion of the buffered data and saves the remainder as prehistory for the next event. This process is repeated continuously.

EVENT DETECTION HARDWARE

The event detection instrument operates by comparing voltage signals on each system channel with an adjustable trigger voltage. When the threshold voltage is first exceeded, a timer is started. If additional crossings of the trigger threshold by other channels amount to a given number (user adjustable between four and nine crossings) within a set time interval, an electronic pulse is transmitted to the UNIX workstation to indicate that a transient event has been detected. The time interval over which triggers are counted is set so as to exceed the maximum expected travel time across the geophone array for locatable events.

In order to prevent spurious triggering, the event detection hardware must also screen out noise that, occurring simultaneously on several channels, may mimic the onset of a transient event. Such noise may be generated by the shearer or environmental sources. The system screens noise on each channel by gradually increasing the triggering threshold according to the duration and amplitude of the noise. Thus, relatively long or recurring noise signals in a given channel build up and maintain a high voltage threshold; this keeps the noise from repeatedly triggering that channel.

UNIX DATA ACQUISITION SYSTEM

The UNIX workstation is equipped with an analog-to-digital (A/D) processing system, which operates independently of the workstation host processor. As configured for coal mine monitoring, this A/D system converts analog voltage signals to digital values with 12-bit resolution at the rate of 5 kHz per channel, or an 80-kHz aggregate rate for the 16 system channels. The converted values are stored in buffers holding 1,000 samples of the signal per channel. Three successive buffers store the digitized signals corresponding to one transient event.

Two programs, one for transient capture and another for general-purpose processing, were developed to control the workstation monitoring system. The transient capture program interfaces directly with the digitizing system, and obtains both transient and sampled data from the digitized data buffers provided by the A/D processor (fig. 9). When a valid transient event signal is detected, the transient capture program writes the corresponding data buffers to a disk file. The continuously sampled data are obtained from every buffer provided by the A/D processor, whether or not a transient event has been detected. These samples are selected by dividing each data buffer into a set of 16 sequential search windows for each channel. In each search window, out of four evenly spaced samples, the voltage measurement with the greatest absolute value is selected. The 16 maximum values thus selected for each channel are then put into a special memory-based storage system known as a "UNIX message queue" (appendix B). At this point, the general-purpose program takes over the processing of the continuously sampled data.

The general-purpose program polls for data at 1-s time intervals, first removing sampled data from the message queue and subsequently checking for new transient capture files. The sampled values obtained from the queue are accumulated over 1-min bins and displayed in 1-day charts beginning and ending at midnight. If there is a new transient event file, the processing program calculates and displays the latest update of event locations and rates.

SUMMARY

This report has described a newly developed microseismic monitoring system that has been installed at an active underground longwall operation. The system acquires transient event and continuous microseismic data and has the capacity for the simultaneous acquisition of pressure, closure, or other near-static measurements. Analysis operating concurrently with data acquisition makes preliminary information available on-site. The inclusion of analysis and display functions in the on-site operation makes it possible to test research concepts as they are developed and provides the mine with data that may assist operating decisions.

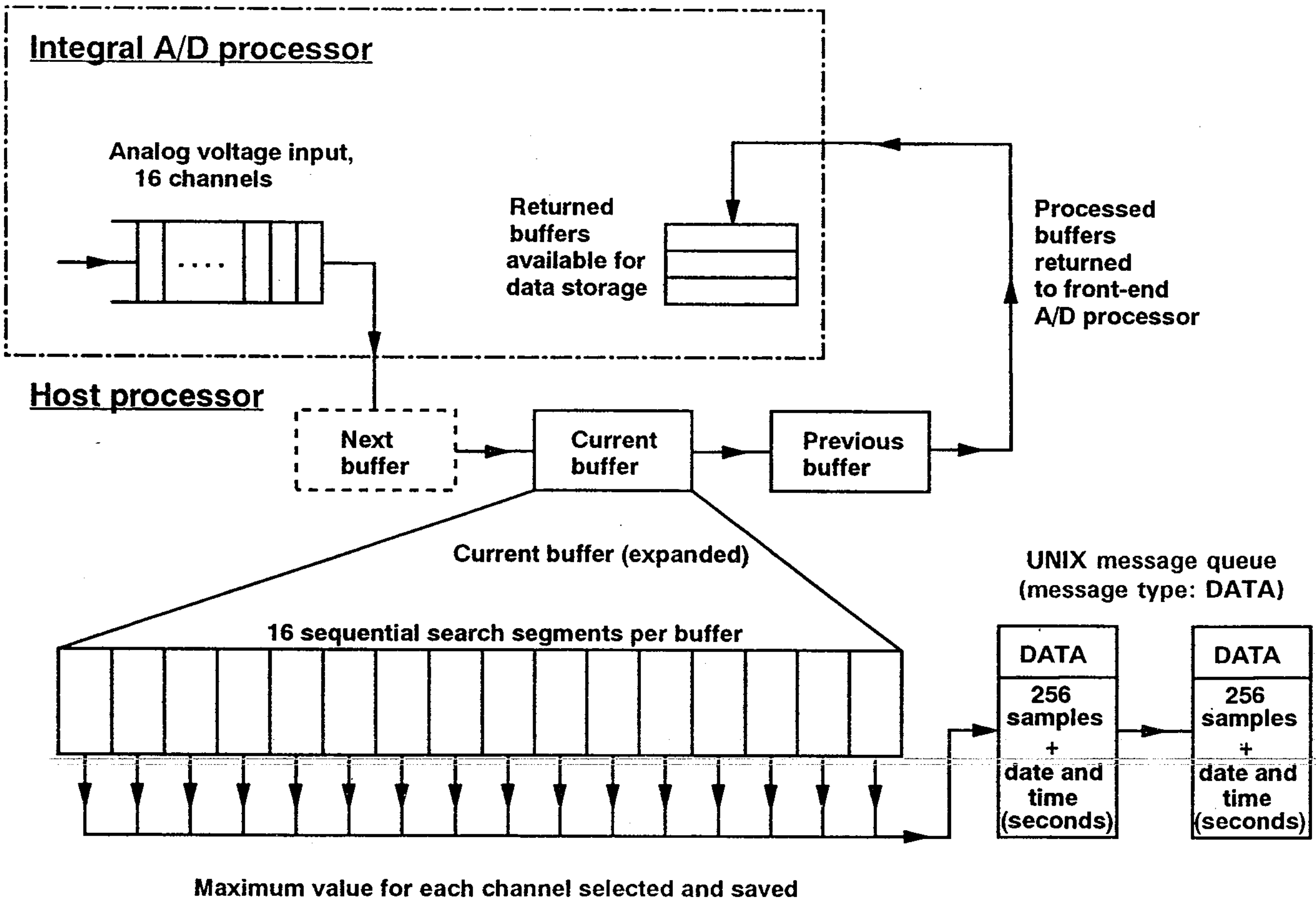

Figure 9.—Transient and continuous data acquisition system. The integral A/D processor continually provides digitized signals in buffers holding 1,000 samples per channel.

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APPENDIX A.—FACTORS AFFECTING THE CONTINUOUS SAMPLING SYSTEM

The continuous sampling system is an experimental technique to evaluate the level of microseismic or other signals in the vicinity of each geophone in the USBM monitoring system. The application of the system is to detect the movement of the longwall shearer and to measure microseismic activity that may not, because of size or location, trigger the transient capture system.

The information provided by the continuous sampling system consists of four statistical parameters that are intended to represent what may actually be occurring, either a set of microseismic events local to the detecting geophone or rock noise caused directly by the impact of the shearer on coal. These parameters are calculated for each geophone channel from samples obtained within a set time period, currently 1 min. The parameters are the sum of the (absolute) voltages exceeding a given threshold, the count of these voltages, their absolute maximum value, and their average value.

The degree to which the calculated parameters actually represent the signal sources depends on four major factors. These are the algorithm used to obtain the samples, the available space in the UNIX message queue, the sampling time period in which the samples are compiled, and the choice of the parameter derived from the samples. How these four system characteristics have their effect is discussed below.

The A/D processor continuously acquires data buffers that hold 1,000 samples for each channel. The data obtained by the continuous sampling system are derived from this succession of buffers. It is at the buffer level that this acquisition system is continuous. Each buffer is divided into a set of sequential search windows. In each window, sized so as to be small in relation to the duration of a typical microseismic event (12.5 ms versus 20 ms minimum), four equally spaced samples are examined and the voltage with the maximum absolute value is obtained and stored. The number of samples that can be examined in each search window depends on how well the computer can keep up with the calculations. The adequacy of the number can be established by the measure of correspondence between measured and known or expected results. Testing with artificially generated signals having frequencies in the 50- to 400-Hz range indicated that four samples are sufficient.

The relation between the sampling time period and the rate at which the source signal changes affects the precision of the results that can be derived from the calculated parameters. For instance, as the shearer moves across the longwall panel, the peak voltage amplitude detected at a geophone directly in line with the shearer should increase when the shearer is moving toward the geophone and decrease as the shearer moves away from it. The position of the shearer relative to the side of the longwall panel can then be established from a scale of voltages. The precision of this location depends in part on how much the signal changes during the sampling time period.

The ability of the sampling system to keep up with the flow of data depends on the total amount of storage space available in the UNIX message queue and on the relation between the rates at which data is written into the queue and read from it. Data writes occur five times per second; data reads, on the other hand, occur either once per second or whenever the data reading program has finished an uninterruptible task such as writing data to disk or calculating the location of a microseismic event, which takes about 1 s. There are also various unpredictable delays in getting the data read out of the queue. These are due to the multitasking nature of the UNIX operating system, which will temporarily pre-empt the reading program in order to run another task such as a screen update or an operator-invoked program. To allow for delays of all types, the queue for this acquisition system was allocated with enough space for 10 data entries (2 s worth of data), all of which can be read in a fraction of a millisecond. In practice, some data gaps show up but this amounts to several seconds in a 1-min time period. In field tests under conditions of ordinary processing and display, the continuous sampling system accurately tracked a constant amplitude signal of a frequency (400 Hz) exceeding the maximum expected frequency of transient events for this monitoring array.

The choice of statistical measure is another important factor. Other parameters, in addition to the four current parameters, also might be obtained. Among these statistical parameters are the modal count and the modal voltage within each time period as well as the sum of the squares of the voltages (as a measure of energy). The ability of the computer to keep up with the continuous flow of data is a major consideration in this regard, particularly in the case of the sum of squares. It is likely that some form of modal measurement will be tested experimentally, since the mode should be somewhat less noisy than the other parameters.

Although the continuous sampling system is showing useful results immediately and has the capacity for further applications, particularly in relation to destressing activities, this system has two major deficiencies in comparison with a transient capture system. One is intrinsic to the system and the other is related to the experimental and statistical nature of the system. First, since the data provided by the continuous sampling system are greatly undersampled (80 samples per second versus 25- to 800-Hz signal frequency range), there is no spectral information. Second, unlike the transient capture system, the continuous data acquisition does not provide event-based information. This may be a correctable deficiency since it is possible to define an artificial event by establishing two voltage thresholds and a minimum interevent time that would correspond to the start and end of such an event. Even with this technique, however, the system would not provide a reliable measure of single events, but rather an indication of when the average or total number of local events is rising or falling.

APPENDIX B.—USES AND OPERATION OF THE UNIX MESSAGE QUEUE

A message queue is one of several methods provided under the UNIX operating system for independently operating programs to share information. Other methods are signaling, semaphores, shared memory, pipes, and simple input-output redirection. A complete description of these methods generally is available in UNIX manuals and books on UNIX. Only the message queue will be described here.

There are several features that make a UNIX message queue particularly convenient and useful in the area of program communication. In the current application, the two most important are that the data may be in any format and that the operating system takes care of the details of synchronizing read-write access to the queue. Other characteristics of the message queue are that data entries are identified by a user-defined type number and that access to the queue is regulated by a key code, which can either be defined by the cooperating programs or derived for the cooperating programs by a system call.

In the USBM coal mine monitoring system, a UNIX message queue is used for several purposes. The primary use, as mentioned in the text, is to transfer data samples from the data acquisition program to a processing program. There are two further uses for the message queue. These are related to convenience in operating the monitoring system and to the maintenance of continuous data acquisition when data files are being archived. For convenience in processing, event file names are set by month, day, year, and a numerical file index, which simply corresponds to the time-ordered sequence number of the event on the given date. Every day at midnight, the file-naming system changes. When this happens, the data acquisition program posts the new file-naming system to the message queue. The processing program detects the new-name message and begins polling for files under the new naming system as soon as there are no remaining files under the previous system. In addition to providing a flexible way to maintain a convenient file-naming system among cooperating programs, the UNIX message queue has use in maintaining continuous data acquisition when previously acquired data are being archived on magnetic tape. In order to avoid conflicts, the data acquisition program must write newly acquired data to a directory other than the directory being archived. Via a simple program that writes the new directory name to the message queue, the system operator sets the acquisition program to write data files to a new directory. As in the regularly scheduled file name change, the naming system based on the new directory is automatically passed on to the processing program.

Figure 9 (in the main text) shows how continuous data acquisition operates in conjunction with transient data capture. Figure B-1 is a schematic of the message queue.

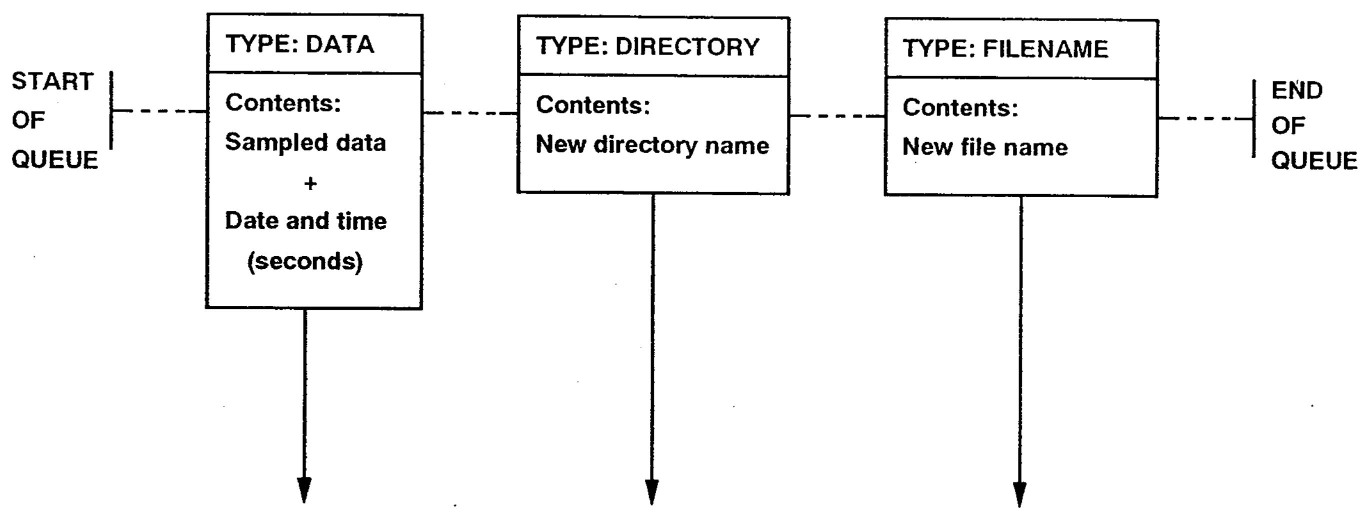

Figure B-1.—Data and file control. The message queue holds new file and directory names as well as data.

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