A Newly Developed Computer Graphics System for the Display of Underground Mine Environments

DUANE L. ABATA AND EDWARD F. FRIES

Abstract—**A newly developed computer graphics software package designed for the display of remote sensor information, such as underground air quality data, on a color graphics video screen is discussed. The software also has trending, predictive ventilation, contaminant, and mine fire capabilities. It was developed at Michigan Technological University under US Bureau of Mines contract H0212024. The package utilizes a unique system of display indexing that provides a simple, efficient method of recalling a series of mine schematics, detailing an underground operation and an alarm display and acknowledgment scheme that provides an effective method for identifying problem areas that may exist in the mine network. The package also permits the display of trend plots, which an operator uses to review a particular sensor value as a function of time over a period of several days. The software package has been written in Fortran and has been designed for use with a specific hardware system, although it can be modified for other hardware installations.**

Introduction

FOR THE PAST several years the US Bureau of Mines has been researching the application of a totally intrinsically safe environmental mine monitoring system that permits remote real-time data acquisition of the underground mine environment and displays this information at a centralized location above ground [1], [2]. This monitoring system is schematically shown in Fig. 1. The Bureau has seen, through its research in the mine monitoring program, that the utility of any monitoring system is limited only by its interface to the operator. The usual technique of printouts and cathode ray tube (CRT) displays is inadequate when the system is monitoring many parameters at a large number of locations in a mine. In the event of a problem, the operator is flooded with warning messages without regard to priority. The use of a color graphics display is one avenue to presenting the data in a clearer manner. A Bureau of Mines research contract (H0212024) with Michigan Technological University has developed a color graphics system that displays a mine map containing real-time sensor output data, provided by a mine monitoring system.

The purpose of the color graphics display system is to enhance an operator's understanding of the mine environment and to improve the operational maintenance and management reporting procedures. The color graphics system has a large capacity, providing about 2000 pictorial displays, and can be modified for almost any application. The indexing system allows the mine and mine components to be broken into groups, each group with its own informational display page. These groups are user-assigned but typically include mine ventilation schematics, electrical power distribution, conveyor systems, pumping systems, ventilation systems, and fire systems. In addition to the display software the color graphics system also has the capabilities to predict environmental conditions at specified underground locations at future time intervals, based on sensor input data [3], [4]. This predictive capability is also discussed.

The resulting code, described in this paper, was written in Fortran. The version used for compilation is Microsoft Fortran 80 [5], which is compatible with the American Standard Code for Information Interchange (ASCII) Fortran

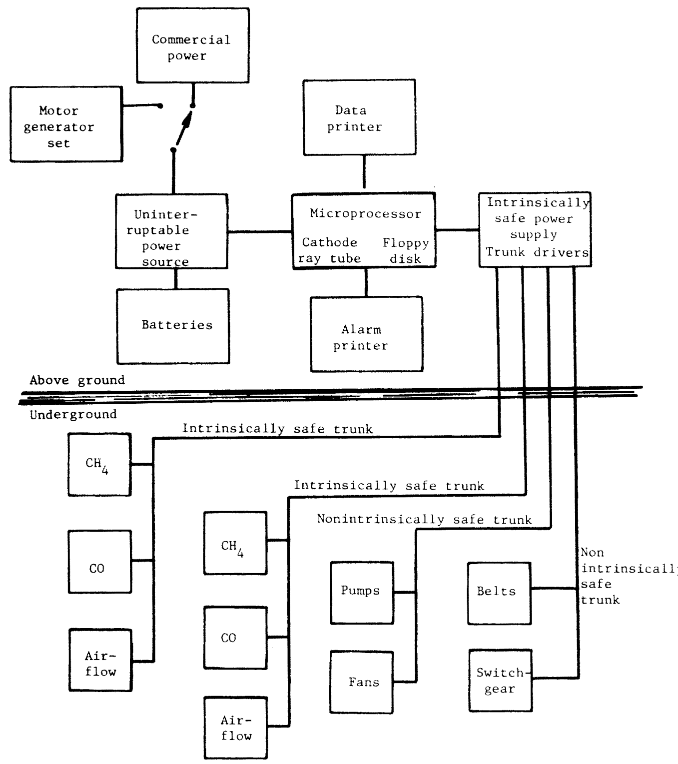


Fig. 1. Mine monitoring system.

Paper PID 86-33, approved by the Mining Industry Committee of the IEEE Industry Applications Society for presentation at the 1984 7th WVU Mining Electrotechnology Conference, Morgantown, WV, July 24-27. This work supported by the US Bureau of Mines under contract H021204. Manuscript released for publication August 10, 1986.

D. L. Abata is with the College of Engineering, Michigan Technological University, Houghton, MI 49931.

E. F. Fries is with the Pittsburgh Research Center, US Bureau of Mines, Pittsburgh, PA 15236.

IEEE Log Number 8612028.

IV developed for mainframe use, with a few minor restrictions caused by the smaller memory availability of the microprocessor. These restrictions are of no concern as the program is easily understood by anyone with a working knowledge of Fortran IV. Because of publication limitations, the code package is not reprinted here. It is available from National Technical Information Services (NTIS) [6].

Hardware System Description

Mine Monitoring System

The Mine Monitoring System is a commercially available microcomputer-based real-time data acquisition and control system using a common communications trunk with four wires: two for data and two for dc power [7]. The central station on the surface is equipped with a CRT display and a floppy disk drive. Dual printers provide backup hard copy of data and alarms.

The CRT displays continuous readings of up to six monitoring or control points on the lower portion of the screen. The center portion is interactive with the user, allowing him/her to enter commands to monitor, control, define, or change any feature of the system. The upper portion displays any change of status, which must be acknowledged before it can be deleted. This portion can display a maximum of twelve points and has a flashing indicator for pending alarms.

A high-performance disk system that provides 256 kbytes of additional program memory is used. The disk allows the user to store frequently used data as well as programs on a magnetic medium, thereby forming a nonvolatile memory. On startup the program is down-loaded from the disk into the random access memory (RAM) (64 kbytes), from which it may be executed by the central processing unit (CPU). A programmable read-only memory (PROM) (8 kbytes) contains the system boot strap and monitor. The disks are 8-in, single-sided, and single-density for increased reliability.

Color Graphics System

The overall system hardware consists of two principal components: the display screen with an associated console keyboard and the microprocessor–computer. Both components are commercially available [8], [9]. This hardware is in addition to that required by the mine monitoring system.

The graphics display screen is an eight-color CRT intelligent data terminal and receives control data either from the keyboard or through a serial port from an outside source such as a host computer. Standard display features include 64 upper-case ASCII alpha and numeric characters with 80 characters per line and 48 lines per screen page presented on a 19-in monitor. A resolution of 480 H × 380 V pixels is possible, with each pixel having any one of the eight specific colors in the high-resolution graphics mode. This package also contains a graphics command processor that includes commands for vectors, arcs, circles, and rectangles, as well as time plots. For specific details the reader is referred to the manufacturer [8].

The microprocessor is a Z80-based (64-kbyte, 8-bit processor), multiterminal, multitasking device with 208 kbytes of dynamic random access memory (RAM)—48 kbytes of usable space for each of the four users. It is equipped with an 8-in hard disk drive with a capacity of approximately 8.5 Mbytes and a double-sided, double-density 8-in floppy disk drive with a formatted capacity of 1.25 bytes. The microprocessor operates under the MPM/II multiuser disk operating system with special software utilities including fast data backup and restore programs. The 8-in floppy disk is compatible with the IBM 3740 format. The computer is equipped with a parallel line printer port (Centronics compatible) and seven (RS-232C standard) serial ports for terminals, printer, and communication support. For further specifications and operation of the system the reader is referred to the manufacturer [9].

Overview of Graphics Software

Description of the Graphics Organization

The color graphics display compromises three types of display pages: the master index page (MIP), the group index page (GIP), and the detail display page (DDP). These pages are arranged in a manner similar to a book. The MIP corresponds to a table of contents identifying all the chapters in the book; therefore only one exists in a system. The GIP corresponds to section headings within a chapter. The DDP corresponds to the specific contents of each section displayed with various graphics pictures stored within each group. Each group may have as many DDP's as necessary, limited only by the available memory in the computer. Fig. 2 shows the relationship between the three types of display pages. Notice that the DDP's are the desired pages that contain the detailed pictures. The MIP and the GIP pages are used to organize the information for easy retrieval.

The master index page identifies all the groups that exist within the system. The color in which the names of the groups are displayed indicates the status of that particular group. White is used for a normal display or normal status. Yellow indicates that the group contains one or more acknowledged alarms. Red indicates that the group contains one or more unacknowledged alarms. An example of an MIP is shown in Fig. 3.

Unacknowledged and acknowledged alarms alert the operator to an abnormal condition in the mine. These alarms are triggered automatically by the system when an analog or binary sensor value exceeds some preset trigger level. Initially, when an alarm condition occurs, the alarm is called an unacknowledged alarm and is displayed in red. The operator must manually acknowledge the alarm condition, after which the alarm becomes an acknowledged alarm and is displayed in yellow. The acknowledged alarm condition will continue until the sensor value falls below the preset trigger level.

The group index page is an index of all the detail display pages within a particular group. Each GIP has an assigned group number associated with it. The alarm status of each DDP within the GIP is indicated by a color similar to the MIP. An example of a GIP is shown in Fig. 4.

The detail display pages (DDP's) are display pages contain-

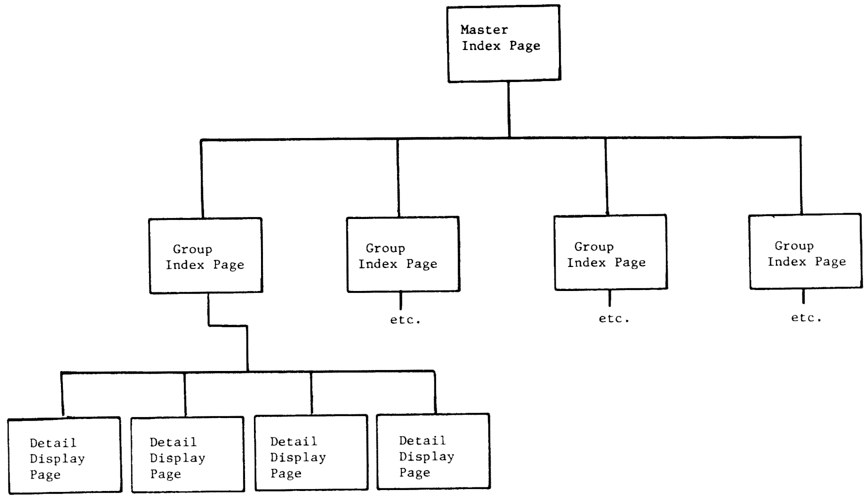


Fig. 2. Relationship between MIP, GIP, and DDP.

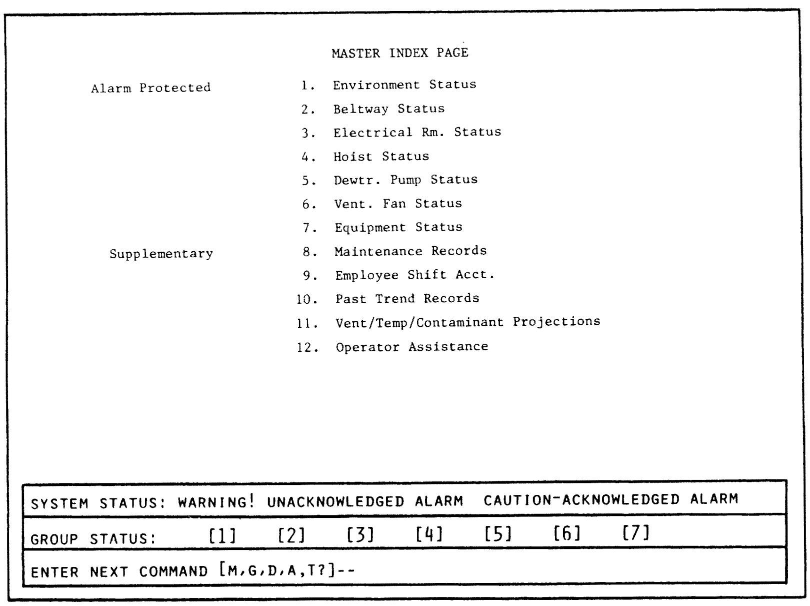


Fig. 3. Example of MIP. (Colors not shown.)

ing descriptive diagrams, symbols, or schematic maps that detail the equipment or area on which an alarm event or occurrence is displayed. A DDP can take any form desired to best illustrate the monitored condition to the observer. Any information on these DDP's can be dynamically updated manually by the operator. This includes all analogs assigned to each DDP. Typically one would not want to crowd information on a screen but would divide a DDP into two or more pages to improve clarity. Binary points and analog values can only be assigned to one DDP. This single assignment ensures that the operator associates a group of alarms with a particular DDP. An example of a DDP is shown in Fig. 5.

Consider the following example: the MIP outlines or indexes the entire mine system into specific groups. A particular GIP within the mine system may index the conveyor belt system. In the case of an alarm condition the associated DDP listed on the GIP will change color from normal (white) to alarm (red). This will indicate to the operator the location of the failed conveyor and the DDP that should be selected for specifics of the failure. The operator then can refer to the specific DDP and, after display, immediately identify the location and type of alarm condition.

A status box is displayed on the bottom of the screen and is reserved for instantaneous and continuous indication of alarms (see Figs. 2–5). It is continually and automatically updated by the processor and displays whether or not there are acknowledged or unacknowledged alarms within the system and what groups have acknowledged alarms within them.

An additional display called a trend plot is available for display of historical information. A trend plot is a two-dimensional plot or graph of a given sensor value as a function of time. The sensor value in an adjustable scale on the ordinate axis is plotted against time in days on the abscissa axis. Sensor values are continually updated and stored in appropriate data files by the system. When a trend plot is called, the operator must specify which sensor he/she wishes to display on the trend plot. The graphics program then reads the appropriate data file, adjusts the axis values to optimize display of the full

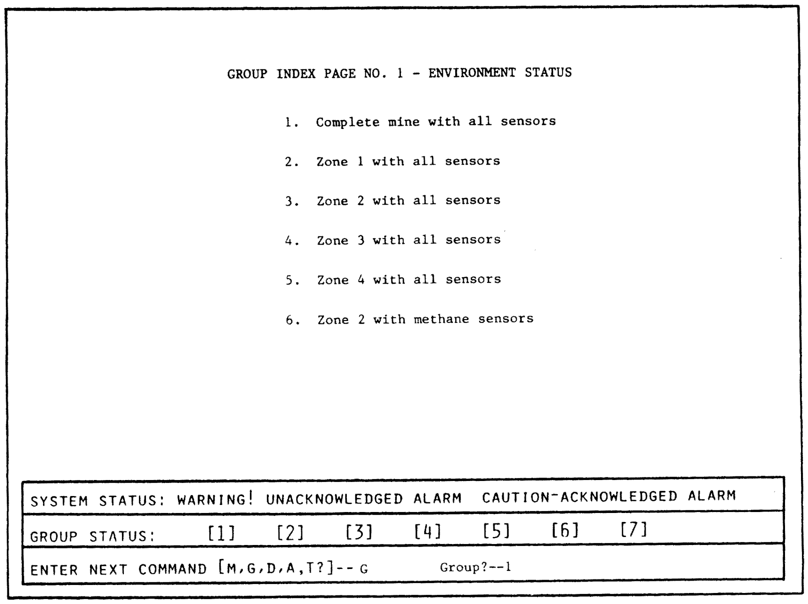


Fig. 4. Example of GIP. (Colors not shown.)

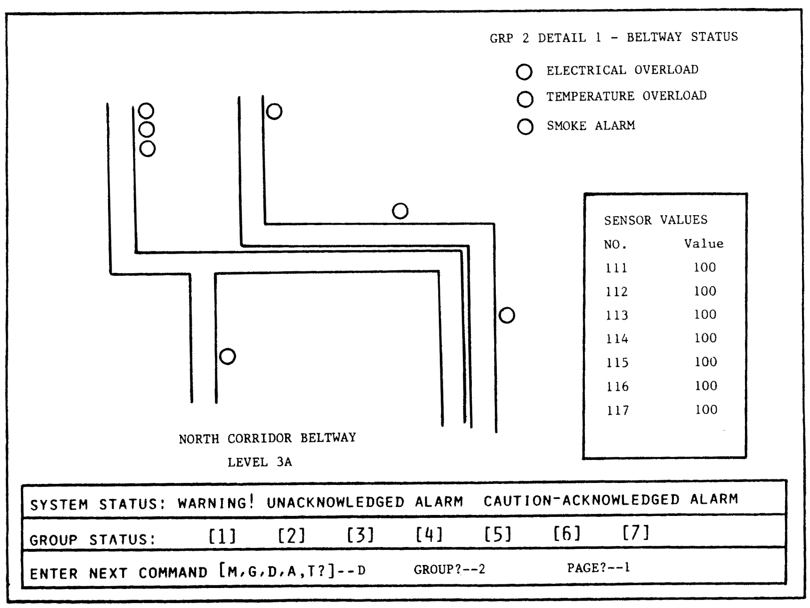


Fig. 5. Example of DDP. (Colors not shown.)

screen, and displays the requested information. Trend plots of air flow rate for a particular corridor over a 30-day period or of a contaminant such as carbon monoxide over a 30-day period are typical examples that a mine manager may want displayed. An example of a trend plot is shown in Fig. 6.

Screen Operation

The operational procedures of the colors graphic system are designed for ease of operation. The data request system is designed to minimize errors and to speed response. Upon initiation of the computer graphics code, a title page is displayed on the screen. The operator then enters the carriage return to continue with the program. When the carriage return is entered the screen clears and the blue status box is displayed on the bottom of the screen as shown in Figs. 2–5. The first line in the blue status box gives the overall system status. This line will display one of two flags, the UNACKNOWLEDGED ALARM flag or the CAUTION: ACKNOWLEDGED ALARM flag, depending upon the alarm condition.

Predictive Capabilities

A mine fire and ventilation code that simulates ventilation of a specific mine network under various mine conditions, including fires [10]–[13], and operates on a mainframe computer was developed by Michigan Technological University under a previous BuMines contract. This code describes airflow, temperature, smoke, and contaminant concentrations, such as methane, for each roadway and junction in a specified mine network. Here the word "network" implies an underground scheme of interconnecting tunnels, passageways,

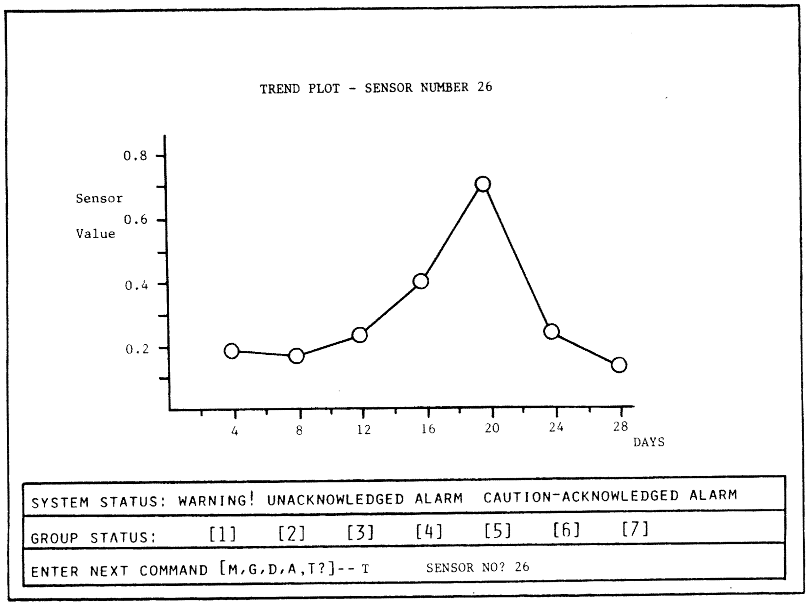


Fig. 6. Example of trend plot. (Colors not shown.)

stopes, drifts, and shafts of varying complexities in a variety of environments containing dust, methane gases, and/or other possible pollutants.

It is obvious that such a computer model that predicts ventilation in an underground scheme is extremely helpful to mining engineers who have been assigned the task of ventilating the mine and maintaining a proper environment for personnel working underground. The code identifies potentially critical conditions and their location in the mine, allowing the mining engineer to correct the conditions before they actually exist.

A task that was completed as part of the color graphics system was to allow the mainframe computer code to operate within the restrictions of a Z80 microprocessor with multiuser, multitasking capabilities. Because memory restrictions were imposed it was necessary to divide this program into three separate programs. These programs, more fully explained in [6], are summarized here.

1) Program MINEVENT: predicts the ventilation patterns in an underground mine under normal ventilation conditions.
2) Program MINECONT: predicts the concentration distribution throughout a mine of a contaminant that may be present in the underground air or generated within the rock (i.e., methane).
3) Program MINEFIRE: predicts the ventilation patterns in an underground mine in the event of an underground mine fire, reports the temperature distributions throughout the mine, and calculates the concentrations of a mine-fire-generated pollutant such as smoke or carbon monoxide.

MINEFIRE is actually a set of two separate programs because it is too large to fit within the bounds of the 48-kbyte user memory segment. These two subprograms are entitled MINEFIRE and VENTFIRE. All four programs fit separately within the 48-kbyte memory restriction. All share common input data files and a common output file. This common output file is read by a program, MINECOLR, which assigns appropriate graphics colors to the predicted values of airflow, contaminant, and temperature. When executed, the graphics programs, MAINGRAF and SUBGRAF, read this output file and display the predictions in multicolor schematics on the screen.

The time required for calculations depends upon the particular mine. Program MINEVENT requires between 30 s and several minutes to complete its calculations. Program MINECONT is a bit faster, requiring between 10 s and 1 min to complete calculations. Program MINEFIRE could take several minutes to reach convergence, depending upon the size of the mine and the number of iteration loops before calculations are finalized.

Another important limitation is the size of the mine that can be processed by the microprocessor. A large mainframe facility equipped with many kbytes of memory can handle much larger mine configurations than the smaller 64-kbyte machine. The microprocessor code is limited to approximately 100 airways and 100 junctions. This airway and junction limitation is not as imposing as it may seem, since in very large mines a series of interconnecting passageways can be represented as one passageway with an equivalent resistance factor introduced into the input data file. Thus even large mines can be operated with the microprocessor programs, i.e., any mine can be reconfigured and reduced in complexity by equivalent airways and junctions.

Conclusion

A computer graphics display system has been developed under a Bureau of Mines contract to accept information from a computerized monitoring system to assist the operator in managing mine operations. The system allows display and trending of remote sensor information. The system can calculate and display the ventilation and environmental parameters in each branch of an underground mine by using the real-time information from a few instruments. Future forecasting predictions can be modeled for various environmental scenarios.

Acknowledgment

The authors would like to acknowledge several individuals who were very helpful with the project: Marilyn Nagel and Judith Wise, MTU, who assisted with program development; Mohammed Mohammed of Conspec, who conceptualized the indexing system used in the graphics code; and many others who offered and contributed assistance with the program and hardware.

References

[1] R. A. Watson, "An intrinsically safe environmental monitoring system for coal mines," in *Proc. Sixth West Virginia Univ. Conf. on Coal Mine Electrotechnology*, West Virginia Univ., Morgantown, WV, July 28–30, 1982, pp. 345–360.

[2] E. F. Fries, "A progress report on the Bureau of Mines mine monitoring systems at the Black River and Bruceton safety research coal mines," in *Proc. Sixth West Virginia Univ. Conf. on Coal Mine Electrotechnology*, West Virginia Univ., Morgantown, WV, July 28–30, 1982, pp. 361–377.

[3] D. Abata, "The prediction and display of underground mine environments with microprocessor technology," presented at the SME–AIME 1984 Fall Meeting and Exhibit, Denver, CO, October 24, 1984.

[4] D. Abata, A. Baumgartner, and M. Nagel, "Calculation and display of ventilation airflow in an underground mine utilizing a computer graphics system," in *Proc. Sixth West Virginia Univ. Conf. on Coal Mine Electrotechnology*, West Virginia Univ., Morgantown, WV, July 28–30, 1982, pp. 388–406.

[5] Microsoft Fortran 80, Microsoft Company, 10800 N.E. Eighth, Suite 819, Bellevue, WA 98004.

[6] This report can be obtained from the National Technical Information Services (NTIS), US Department of Commerce, Springfield, VA 22161, NTIS No. PB 85-203826.

[7] Conspec Controls, Inc., 901 Fuhrmann Blvd., Buffalo, NY 14203, and Conspec Controls, Inc., 44 Martin Ross Avenue, Downsview, ON, M3J 2K8, Canada.

[8] *The Intecolor User's Manual for 8000, 8300, and 8900 Series Intecolor Terminals*. Intecolor Systems Corporation, Intecolor Drive, 225 Technology Park, Atlanta, GA 30092.

[9] *Users/Technical Manual*. Quay Corporation, P. O. Box 783, Eatontown, NJ 07724.

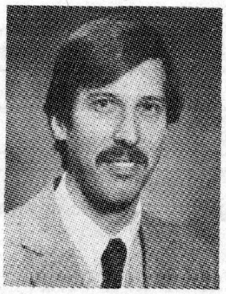
[10] R. E. Greuer, *A Study of Mine Fires and Mine Ventilation: Part I*. Contract S024132, final report, 1977.

[11] R. E. Greuer, "A new computer program for the design of ventilation emergency plans," in *Proc. Second Mine Ventilation Congress*.

[12] R. E. Greuer, *Precalculation of the Effect of Fires on Ventilation Systems of Mines*. US Bureau of Mines research report, three volumes, 1980.

[13] US Bureau of Mines, "MNVNTLTN subsystem for computer simulation of ventilation systems under the influence of mine fires," in *Program Users Manual and Program Maintenance Manual*. Spec. Pub., Feb. 1980.

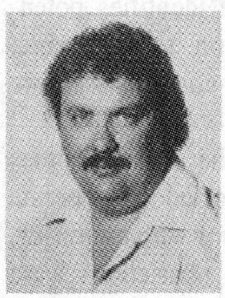
[14] Michigan Technology University, *Video Display of Mine Environments*. Contract H0212024, BuMines OFR 55-85, 1984, 229 pp.; NTIS PB 85-203826.



Duane L. Abata received degrees from the University of Wisconsin in the specific areas of combustion and thermodynamics.

He is currently the Associate Dean of Engineering in the engineering college at Michigan Technological University in Houghton, MI. He is a tenured faculty member in the Department of Mechanical Engineering and Engineering Mechanics. He began research work for the mining industry at the onset of his appointment at Michigan Tech and has worked with various aspects of combustion and explosives, toxic gases from explosives, and underground ventilation.

Dr. Abata has received numerous awards for his research and teaching and has published several papers in the areas of mining and mechanical engineering.



Edward F. Fries was born in Chambersburg, PA in 1952. He received the B.S.E.E. degree from Drexel University, Philadelphia, PA in 1975.

He is employed by the United States Bureau of Mines in Pittsburgh, PA, and has been involved with the implementation of mine monitoring and control systems for the mining industry for over ten years. He is presently part of a team researching applications for expert systems and artificial intelligence in the mining domain.