A MINIATURE DATA ACQUISITION SYSTEM WITH LED WARNING LIGHTS

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ABSTRACT

Researchers at the National Institute for Occupational Safety and Health have developed a miniature data acquisition system (MIDAS) that can measure resistance changes and temperature, store data for later retrieval, and illuminate LED lights. This instrument can be used with strain-gaged bolts, cable bolts, CSIRO stress-measuring gages, string pots, and any other instrument that uses single-ended, resistance-type gages. MIDAS has the capability to measure up to 16 gages at preset time intervals and store more than 2000 scans, yet is small enough to fit in a 35-mm hole. Because the MIDAS consumes little power, a 9-V alkaline battery will operate the system for 6 months. Data from the MIDAS can be sent to a PC via an RS232/RS485/IRdA port.

A software program was written to set operation parameters, graph data, and store all information directly to a spreadsheet. Three LED lights change from green to yellow then red based on reading levels and/or rates of change. This feature can be used with different types of gages to warn miners of possible rock instabilities. The MIDAS has received MSHA experimental permissibility approval and is currently being tested at several mines.

1. INTRODUCTION

Roof falls are a leading cause of injury and fatality in underground mines in the United States. Mine Safety and Health Administration (MSHA) statistics from 1997 to 2001 show that fall of rock from a mine roof was the leading cause of injury to all underground mine workers. Of 40,004 reported accidents, 10,438, or 26.1%, were caused by roof falls.

Although studies conducted by researchers from the U.S. Bureau of Mines and the National Institute for Occupational Safety and Health (NIOSH) have demonstrated that geotechnical instruments can be effective in identifying and monitoring ground control hazards, modern rock mechanics instruments are rarely used by the mining industry in the United States. Instead, data are collected by either taking readings with hand-held instruments or installing electronic data acquisition systems. Hand readings are very labor intensive and tend to be collected infrequently. Typical continuous electronic data acquisition systems are large, difficult to use, and expensive, and long lead wires are required to connect sensors to the instruments. In addition, many mines, especially smaller operations, do not have the expertise nor the resources to design an effective instrumentation plan, properly install and monitor a variety of instruments, and analyze and interpret electronic readings obtained from the instruments.

Another problem is that all electronic data acquisition systems must have MSHA approval if they are to be used anywhere but in fresh air in mines that release methane as a by-product. Two companies that used to manufacture general-purpose, MSHA-approved systems no longer do so, which has severely limited the use of such systems.

NIOSH developed a miniature data acquisition system (MIDAS[1]) that addresses these problems. This system has the potential to make the use of geotechnical instruments in underground mines more feasible. The MIDAS can be used with any instrument that uses resistance-type sensors. Several different instruments were developed by the U.S. Bureau of Mines (fully grouted, cable, and friction bolts with strain gages attached; bolt load cells) and NIOSH (rock strain strips) to monitor rock movement (Marshall 2000) and loads on rock bolts (Martin 2001; Signer 2000). The MIDAS is one of the newest instruments developed to measure rock movement and has been given an experimental permit by MSHA.

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[1] The MIDAS has a patent pending, and information regarding licensing or use of this circuit should be directed to the authors.

2. MINIATURE DATA ACQUISITION SYSTEM (MIDAS)

1. Hardware

Recent advances in analog integrated circuits enabled the MIDAS to be small, accurate, power efficient and relatively inexpensive, yet rugged and watertight (figure 1). The heart of the MIDAS is a sigma-delta analog-to-digital converter (figure 2). The specific converter chosen for this design is more sensitive and accurate than other parts of the circuit and can produce nearly 24 bits of useful data at a sampling rate of 2 Hz. When coupled with the rest of the input circuitry, it can resolve approximately 20 bits.

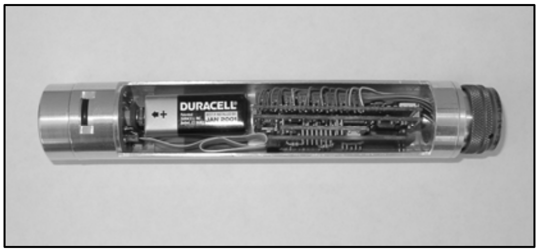

Figure 1.–MIDAS demonstration model

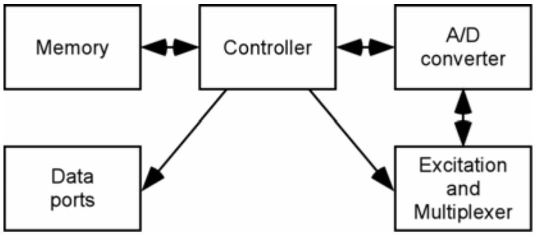

Figure 2.–Block diagram of MIDAS

At the point of input to the converter is an excitation source and multiplexer (figure 3). The excitation source is fixed at 4.5 V and is buffered so that it can power 120-ohm strain gauges with negligible voltage offset. Sixteen input channels connect through multiplexer integrated circuits to the inverting input of the converter. The circuit cycles through the channels in a preset sequence, exciting one channel for each sample to produce a “scan.” The excitation and multiplexer circuitry are arranged in a standard wheatstone bridge configuration and are specifically designed for two-wire quarter-bridge or half-bridge sensors. Completion resistors for the quarter-bridge sensors are included on the circuit board. The reference voltage divider connected to the noninverting input of the converter is also included on board (figure 2).

The converter can be configured for a sampling rate of from 2 to 650 Hz. Maximum resolution is obtained at the 2-Hz update rate. In addition, the converter includes a programmable amplifier having a range from 1 to 64. We have found that the most accuracy is obtained with a gain setting of 8 at a 2-Hz sampling rate. For general use, a gain setting of 2 at a 15-Hz sampling rate also gives excellent results. This setting will reject nearly all ac (60 Hz) interference and still provide nearly 19 bits of useful data.

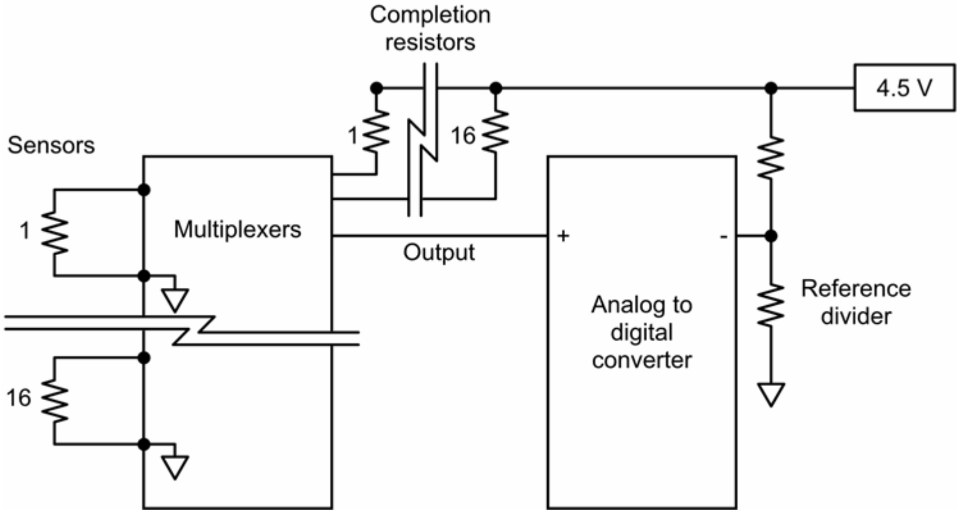

Figure 3.–MIDAS multiplexer circuit

The digital side of the MIDAS is composed of data storage and communication integrated circuits. In addition, an LED warning light feature (figure 4) can be activated. The MIDAS is configured with a memory capacity of 128 kbyte, which is enough memory to hold approximately 2200 16-channel scans and provides enough storage for the long-term, low-scan, rate-testing programs currently in use at several mine sites. The scans are stored in nonvolatile FLASH memory, so data loss resulting from a removed or low-voltage battery is not a concern.

Figure 4.–MIDAS LED lights and serial connector

When stored in memory, each scan is composed of several fields. The first field consists of diagnostic information, such as condition of the battery. The second field is a date and time stamp, and the third field is temperature of the circuit board. The remaining fields contain samples from the sensors. Knowledge of circuit board temperature can be useful when post-processing data to reduce temperature-induced errors from the sensors.

The MIDAS is configured and data are recovered though one of three serial interfaces. RS232 is the primary interface, and the one we have used most often in our testing programs. RS232 allows connection of a MIDAS directly to a personal computer (PC). An RS485 interface, a long-haul, differential signaling interface, is also incorporated into the circuit board. This interface allows communication between a PC and a MIDAS over approximately 1000 ft of cable at 57.6 kbaud. An external signal converter is required at the PC end of the link to convert the RS485 signal into an RS232 signal that can be read by the PC. An IRdA port is also included on the circuit board. This interface allows communication between the MIDAS and computers equipped with IRdA ports through the use of infrared light.

Incorporated in the firmware is a feature that will flash an LED light periodically depending on the data returned from a scan. At the end of each scan, the firmware calculates the difference between reference values and the values of the current samples. A green LED light flashes if any of these differences are below a set threshold, a yellow light flashes if values exceed a warning threshold, and a red light flashes if any samples exceed a danger threshold. The user can set the threshold values, reference values, time between flashes, and flash duration.

Power requirements for the MIDAS are relatively low. Between scans, the circuit draws approximately 18 microamps from the battery. When actively scanning 350-ohm sensors, the circuit draws 28 milliamps. In long-term test programs, a 9-V alkaline battery can power a MIDAS up to 6 months. The low power usage enables the MIDAS to comply with MSHA permissibility requirements that state that the unit (1) cannot generate an electronic spark that could initiate an explosion and/or (2) reduces operating temperatures to below spark-inducing levels. Furthermore, all electronic equipment that operates downwind of the working face must comply with MSHA standards, requiring that batteries must always be changed in fresh air. The MIDAS meets these requirements and has been given permissibility approval by MSHA.

A successor to the MIDAS is currently in development. This circuit differs from the MIDAS in the following respects. First, the memory has been increased to 2 Mbytes from 128 kbytes. Second, power consumption has been decreased to allow longer tests between battery changes. Third, the gain has been fixed at 1 Hz and the sampling rate has been fixed at 15 Hz since this produces acceptable results for most of the tests. Fourth, the size of the device has been reduced while making the unit easier to manufacture and assemble.

2. Software

The MIDAS communicates with an ASCII communication protocol so that all the functionality of the MIDAS can be accessed with a terminal emulator program running on a PC. This approach, however, can be difficult, especially for casual users. Therefore, a Microsoft Windows[2]-based software program was written to communicate with the MIDAS

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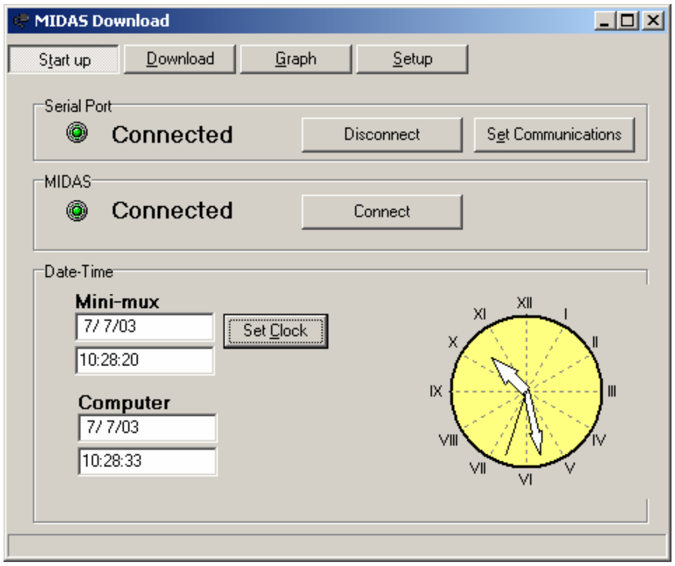
[2] Mention of specific products and manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

for set-up, monitoring, and data download. Simplicity of use was a primary consideration so untrained users could easily operate the system.

The software is organized into four pages: startup, download, graph, and setup. When the software loads, it automatically opens an RS232 serial port to communicate with the MIDAS, and the startup page is displayed (figure 5). The status of the serial port connection is reflected in the color of an LED light. If a problem occurs during communication, the LED light turns red, requesting that the user change the communication parameters of the serial port. If the MIDAS unit is not functioning or is not connected to the computer, then an error box will appear, and the status light will reflect the state of the connection. The "connect" button will attempt to reestablish communications. Also, on the startup page, the user can set MIDAS's clock.



Serial Port
Connected

MIDAS
Connected

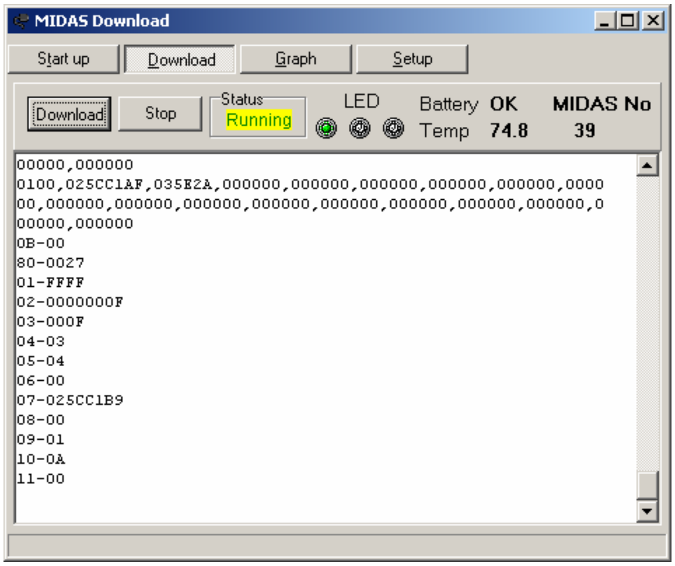
Date-Time

Mini-mux
7/ 7/03
10:28:20

Computer
7/ 7/03
10:28:33

Figure 5.—Start-up window

The primary function of the download page (figure 6) is to download data from the MIDAS to the computer. The data are written to an Excel spreadsheet file when the "download" button is pressed. This page also shows the current status of the LED lights, battery, and temperature. All data from the MIDAS is in hexadecimal format. The software converts the hexadecimal data into both millivolts and microstrain when it is written to the files. The user also starts and stops the MIDAS from this page.



Status: Running
Battery OK
Temp 74.8
MIDAS No 39

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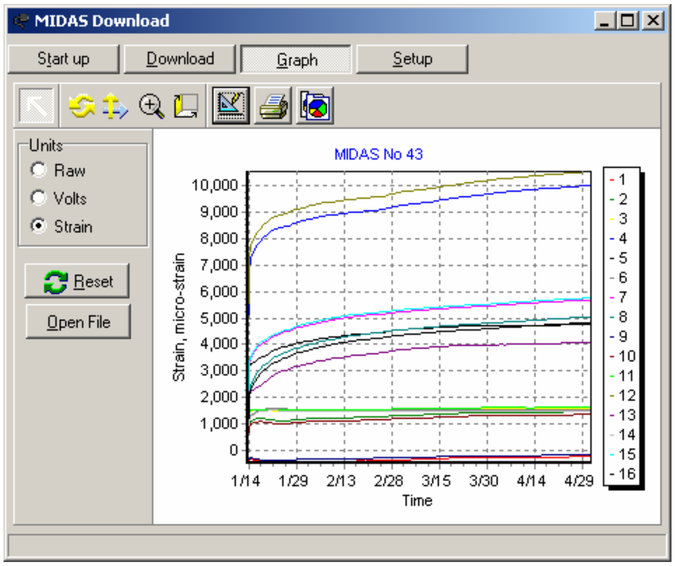
00000,000000
0100,025CC1AF,035E2A,000000,000000,000000,000000,000000,0000
00,000000,000000,000000,000000,000000,000000,000000,000000,0
00000,000000
0B-00
80-0027
01-FFFF
02-0000000F
03-000F
04-03
05-04
06-00
07-025CC1B9
08-00
09-01
10-0A
11-00
```

Figure 6.—Download window

Data can also be monitored or viewed on the graph page (figure 7) of the software. The user has the option of viewing the data in microstrain (the default), millivolts, or raw analog-to-digital converter counts. The graph can be printed and/or copied to the Windows clipboard and pasted in another document. The graph allows full control of titles, axis properties, and graph types. Already-downloaded data can be viewed on the plot by pressing the "open file" button. This currently only allows viewing of strain data.

The setup page (figure 8) is used to set all the operating properties except the clock. The channels that measure strain are selected with check boxes. The scan rate can be set using increments of seconds, minutes, hours, or days. The excitation time, filter cutoff, and gain are set with pull-down menus or edit boxes. The data can be collected in either relative or absolute mode. Relative mode is the default and records changes with respect to when the re-zero button was last pressed. Resetting the MIDAS will erase all data. The "constants" button allows the user to set the threshold values for the LED lights and the strain gage factor for each of the attached sensors. Blink interval and duration can be set to either increase or decrease the amount of light from the LED, which would affect power drain on the batteries. A user can select whether to continue scanning when a low-battery condition is reached or when memory is full. This becomes useful when running the MIDAS connected to a PC, because the PC software can be configured to store scans regardless of remaining memory capacity on the MIDAS.



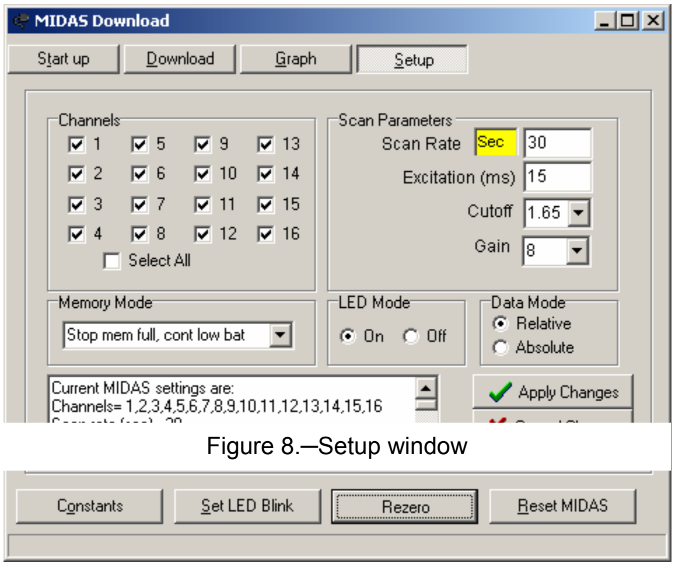
Units
○ Raw
○ Volts
● Strain

Figure 7.—Graph window

The functions of the MIDAS are activated by command codes and parameters. These codes are sent to the MIDAS when the user interacts with the Windows program. Some actions are initiated with the click of a button, while others may require selection from pull-down menus, radio boxes, etc. After the MIDAS receives the command code, it performs the function and echoes the command and parameters.

The MIDAS can only execute one command at a time. Windows users may execute commands faster than the MIDAS can process them. The solution to this problem was to make a queue that could store many commands and send each one after the preceding command was completed. The problem with this approach was that if the MIDAS became disconnected from the system, the commands would wait. Then, if another MIDAS were attached, the previous commands would be sent to the wrong unit. To solve this problem, a time-out function was incorporated that disconnected the MIDAS after a short period with no response. The user would reconnect on the startup page, the command buffer would be purged, and fresh status information could be obtained. The successor to the MIDAS will use a different communication scheme so this problem will be resolved.

3. VERIFICATION TESTS



Channels
☑ 1 ☑ 5 ☑ 9 ☑ 13
☑ 2 ☑ 6 ☑ 10 ☑ 14
☑ 3 ☑ 7 ☑ 11 ☑ 15
☑ 4 ☑ 8 ☑ 12 ☑ 16
☐ Select All

Scan Parameters
Scan Rate Sec 30
Excitation (ms) 15
Cutoff 1.65
Gain 8

Memory Mode
Stop mem full, cont low bat

LED Mode
● On ○ Off

Data Mode
● Relative
○ Absolute

Current MIDAS settings are:
Channels= 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16

Figure 8.—Setup window

Initial verification tests were done in the laboratory by comparing the response of the MIDAS with other data acquisition systems. These tests consisted of applying two sets of strain gages to the same sample, loading the sample, and comparing strain readings. Material with known strain yield points were used, and the samples were loaded past the elastic yield to ultimate failure of the material. The tests showed that the MIDAS could measure to 0.1 microstrain over a pan of 170,000 microstrain at a gain setting of 4.

MIDAS systems were tested for over a year to evaluate any potential problems or malfunctions in both the hardware and the software. During this evaluation, the only problem was that the MIDAS could not communicate during a scan. If the scan interval were short and the scan itself long, communication could be difficult. A solution will be addressed in the next revision of the MIDAS hardware.

To be an effective tool in an underground mine, the MIDAS will have to hold up under extreme temperatures, humidity, electrical interference, mineralized water, and dirt. Tests were set up in three different types of mines: coal, silver, and platinum-palladium. The silver mine is a hot humid environment, while the coal mine undergoes subfreezing temperatures. Five different types of instruments were connected (fully grouted, strain-gaged bolts; strain-gaged cable bolts; strain-gaged friction bolts; rock strain strips; and linear extensometers). Some MIDAS units have been running continuously for over a year and over 100,000 hours of underground operation have been logged.

4. SUMMARY

The MIDAS has proven to be a very dependable unit and can make the use of geotechnical instruments easier and cheaper. It can be used in areas that have been very difficult or impossible to monitor, such as at the working face where large equipment or blasting prevents running electrical wires. MSHA permissibility approval allows monitoring instruments to be used in return air. Software written for operation of the MIDAS makes set-up, data collection, and processing easy. Raw data are converted to engineering units and saved to Excel spreadsheets. When used in combination with strain-gaged bolts, rock strain strips, and/or electrical extensometers, bolt loads or rock movements can be measured and the results made available through LED lights to underground workers so that miners can be warned of hazardous conditions.

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