Published in final edited form as:
Trans Soc Min Metall Explor Inc. 2018 ; 344(1): 62–66. doi:10.19150/trans.8749.

Smart monitoring and control system test apparatus

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Abstract

In underground metal/nonmetal mines, repeated localized short-term exposure to high levels of airborne contaminants can become a serious health issue. Currently, there are no common mechanisms to control or mitigate these short-term high exposures to contaminants. To improve miners' health and safety, the U.S. National Institute for Occupational Safety and Health's Spokane Mining Research Division (SMRD) is developing a smart monitoring and control (SMAC) system for the real-time monitoring of mine air quality, with integrated countermeasures to reduce high concentrations of airborne contaminants in localized sections of mines. To develop and test a SMAC system capable of being implemented in an underground mine, SMRD researchers built a test apparatus incorporating a fan, louver, ducting and sensors combined with atmospheric monitoring and control software. This system will institute effective countermeasures to reduce contaminant levels, improving miner safety and health.

Keywords

Underground ventilation; Health and safety

Introduction

Underground metal/nonmetal mines continue to expand production by employing large equipment in greater numbers and by mining into hotter and more challenging environments which are typically further away from fresh air sources. This challenges the ventilation system to provide adequate quantities of fresh air to the workplace and increases the potential for air contamination that could result in immediate and long-term health and safety issues to miners. Currently, airflow and contaminant concentration in mines are typically based on full-shift sampling, which may not identify repeated short-term exposures to high levels of airborne contaminants such as nitrogen dioxide (NO_2), carbon monoxide (CO), diesel particulate matter (DPM) and dust with high silica content. Repeated short-term exposure to these high levels of airborne contaminants over long periods can lead to serious health issues which are documented in several studies (Attfield et al., 2012; Donoghue, 2004; International Agency for Research on Cancer, 2013). Based on data from ventilation surveys and contaminant measurements, mines often attempt to minimize exposures by

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sending more fresh air to the working areas where contaminant concentrations are found to be high. Real-time monitoring and control allows mines the option to monitor contaminants and implement changes in mine-wide ventilation in real time.

Real-time monitoring and control of the underground mine atmosphere has been a subject of research since its beginnings in Finland at the Outokumpu Pyhäsalmi Mine in 1969 (Seppanen, Laatio and Paakkinen, 1979). More recently, the real-time monitoring and control problem has been addressed using ventilation on demand (VOD) systems (Arya et al., 2012; Hardcastle et al., 2012). A VOD system operates on a global level by controlling fans, louvers and doors to increase airflow to active work areas and reduce contamination in the underground mine atmosphere. However, a VOD system may not be helpful in mines where the airflow is at maximum capacity. Researchers at the U.S. National Institute for Occupational Safety and Health's (NIOSH) Spokane Mining Research Division (SMRD) are developing a smart monitoring and control (SMAC) system for real-time monitoring of mine air quality with an integrated ability to trigger countermeasures to reduce high concentrations of airborne contaminants in localized sections of mines. The SMAC system will be designed, tested and refined in the laboratory environment before being demonstrated in an underground mine. This system will minimize the gaseous contaminants by regulating the airflow locally, but will also potentially employ filtration systems to reduce the airborne contaminants in case the maximum airflow capacity is reached. This paper presents development of the test apparatus for the SMAC system.

Basic design concept

Figure 1 shows an overview of a generic SMAC system. The localized SMAC module is the main component that will be developed in this study. However, a communication module can also be integrated with a SMAC system to acquire data for a mine-wide monitoring system and ventilation modeling. In the SMAC module, airflow, dust, DPM and/or gas sensors feed mine atmospheric data to a data processing module that runs algorithms for automated data analysis, to determine whether the trended data has reached a critical threshold. Once a threshold is reached, the control system initiates engineering controls. An example of such an engineering control would be localized filtration that is introduced into the airflow as needed to capture airborne pollutants when predefined contaminant levels have been exceeded. The data processing module continues to acquire data from sensors to detect a change in the environment, and when the desired safe condition is reached, the control system deactivates the engineering control.

In order to develop and refine software algorithms required for a SMAC system, it was decided to build laboratory test apparatus consisting of a fan whose speed is controlled by a variable frequency drive (VFD) along with a louver, two fiberglass ducts and atmospheric monitoring and control units. The VFD-controlled fan is used for variable airflow velocity in the duct, acts as the inlet, and is the primary mode to control flow velocity. The louver is used as a secondary mode of velocity control and serves as the outlet. Fiberglass ducting was chosen based on weight and ease of fabrication, with two sections of ducting used for ease of maintenance, movement and storage. The atmospheric monitoring units sense real-time atmospheric conditions, and the SMAC system institutes effective countermeasures to reduce contaminant levels.

Hardware implementation

The test apparatus, named the Vent-Tube, is shown in Fig. 2. It consists of two fiberglass tubes: the instrumented tube and the fan tube. The instrumented tube is 0.76 m in diameter and 4.87 m in length, and the fan tube is 0.91 m in length and 0.76 m in diameter. The instrumented tube houses two ultrasonic airflow sensors and two gas sensors, for NO_2 and CO, respectively, which are connected to an externally mounted data acquisition unit. The sensors and Vigilante AQS data acquisition unit are from Maestro Mine Ventilation. Mounted at the outlet end of the tube is a positional louver, measuring 0.61 m by 0.61 m, controlled by Advantech's ADAM-6200 remote input/output (I/O) unit. The inlet end of the tube is kept open for attachment of the fan tube (Fig. 2). The fan tube is kept separate from the instrumented tube by design for ease of handling. The fan itself is an axial flow type with a 0.61-m diameter and is driven by a 0.5-hp, 230-VAC three-phase motor controlled by a Schneider Electric VFD. The outlet end of the fan tube slides into the inlet end of the instrumented tube for performing experiments (Fig. 3). A section view of the Vent-Tube apparatus is presented in Fig. 4, showing the airflow and sensors inside the tube.

Querying data from the data acquisition unit and control of the fan and louver are accomplished using Modbus protocol, an industry standard for data communications (Drury, 2001). Three very-high-frequency (VHF) internet protocol (IP)-capable data radios are used for the wireless operation — a "master" and two "slave" radios. The master radio is connected to a computer acting as the system controller. One slave radio is connected to the data acquisition unit and the louver controller through an unmanaged switch (Fig. 5a), and a second slave radio is connected to the VFD by a Modbus gateway (Fig. 5b).

VHF data radios were selected to simulate data transport over a leaky feeder wireless communications system (Cawley, 1989; Updyke, Muhler and Turnage, 1980), chosen because it is one of the more common forms of underground mine communications. Specifically, Ethernet-capable radios were selected to allow for ease of transition to wireless or hardwired Ethernet data transport if available. The 32 kilobit per second (kbps) radio data transmission rate is more than adequate for the small amounts of data required to monitor and control the SMAC system, even with multiple SMAC systems installed in a mine.

Theory of operation

The Vent-Tube-based SMAC system was designed to mimic the dynamic environment of a localized section of an underground mine — an environment where airflow and airborne contaminants levels could be continually changing. The system works as follows: The fan is switched on at low speed (12 Hz) with the louver set to the 90 percent closed position. Contaminants from a diesel engine's exhaust are then injected into the Vent-Tube by an entry point located on the fan tube section (Fig. 6), and airflow and gas sensor data are queried by the system computer. Should the gas sensors read high concentrations of contaminants inside the tube — 5 ppm for NO_2 and 50 ppm for CO — the SMAC module signals the control unit to fully open the louver. If opening the louver brings the contaminant concentration to an acceptable limit, then the louver is closed. However, if the contaminant levels still remain above acceptable limits, the louver is kept open and fan speed is advanced to a higher speed, further increasing airflow quantity. The required increase in airflow quantity is calculated based on both NO_2 and CO concentrations. Once the contaminants have been purged out of the tube, fan speed is lowered and the louver is closed. Contaminant levels injected into the Vent-Tube can be varied by changing the torque load on the diesel engine. Changing fan speed and opening or closing louvers to adjust airflow is the basic concept on which any mine ventilation system operates. Underground mines use VFD-controlled fans to make more global changes in the airflow, whereas the louvers act as localized regulators for airflow. These principles are being applied in the operation of the Vent-Tube-based SMAC system.

Software implementation

Two of the Vent-Tube test apparatus development goals were to integrate various hardware and software components to work together, and to develop a system to be compatible with those used in the mining industry. The challenge was to come up with a system that would integrate all the sensing and control devices in a single platform to monitor and evaluate the data, and send instructions to the devices as needed. It was, therefore, decided to use an Open Platform Communications (OPC) server for sending and receiving instructions to and from the instruments. The OPC server used is the KEPServerEx from Kepware, which enables communication between multiple sensors using the Modbus protocol (Fig. 7). Communication over the OPC Server is performed using the Modbus protocol because the majority of industrial instruments, irrespective of vendors, are Modbus-capable. Modbus TCP was used for the development of the SMAC system as it allows for communication of data by Ethernet. Any device which uses Modbus RTU requires a Modbus Remote Gateway, which can convert the protocol from Modbus RTU to Modbus TCP.

The Kepware OPC server used in SMAC system development was specifically selected as it is commonly used in industrial automation and process control and can easily integrate a wide variety of automation and control devices. An OPC server can be used for a number of mine processes. For example, it can be used for ventilation system monitoring and control as well as ground control monitoring. Therefore, if a mine is already using an OPC Server, the implementation of the SMAC system will be easier.

MATLAB was used for developing the SMAC module due to its ease in integrating different programs such as an OPC server and database on a single platform. Through the MATLAB OPC Toolbox, a script collects data from the OPC server and implements algorithms developed for monitoring and control. The MATLAB OPC Toolbox allows a seamless transfer of data from the sensors through the OPC server to the database.

Figure 7 shows the architecture of the SMAC system. From Fig. 7, it can be seen that the first component is the human machine interface (HMI), which allows for the display of data trends. The second component, the SMAC module, is the core controller of the SMAC system, which sends and receives monitoring data and control instructions through the OPC server and contains the algorithm to make the necessary changes to the system. The SMAC module queries the OPC server to collect the data acquired from the sensors and store them in a database. The database program used for storing SMAC system data is Microsoft SQL Express, which interfaces with MATLAB scripts using the MATLAB Database Toolbox. A MATLAB script contains the algorithms for monitoring and control checking the contaminant levels, and instructs the system to change the fan speed or open/close louvers by the OPC server.

Summary

Periodic short-term overexposure to airborne contaminants during an operating shift, or over the entirety of a miner's career, can pose serious long-term health issues. An automated system to respond to short-term elevations in contaminant levels by improving localized air quality, by either turning on a filtration system or by bringing in more fresh air during the working shift, will reduce these levels. Through the successful design, in-house fabrication and operational validation of specialized test apparatus, SMRD researchers are addressing the issue of short-term overexposure to airborne contaminants. The hardware components of the test apparatus include two ducts, a louver, a fan, and monitoring and control instrumentation. The test apparatus was designed to simulate the mine environment and to be compatible with common mine monitoring and control systems in relation to future testing and evaluation of numerous mitigation scenarios before deployment of the SMAC system in any underground mine. Potential upgrades to the test apparatus will include DPM and dust sensors, additional tube sections, and filtration units for DPM and dust. The development of a SMAC system is expected to ultimately lead to enhanced miner safety and health.

Acknowledgments

The authors would like to thank Mahesh Shriwas and Nilo Tayag for their contributions to this research and Ken Strunk for creating graphics for the paper.

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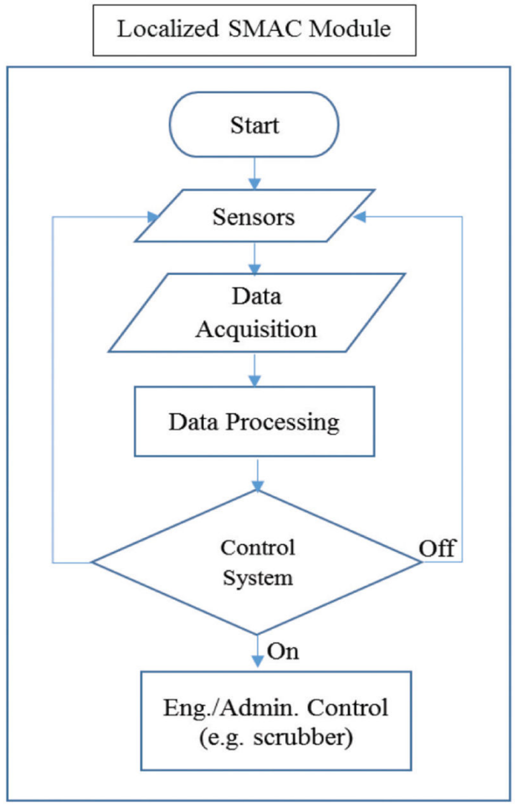

Figure 1 —.
Flowchart showing the layout of a generic SMAC system.

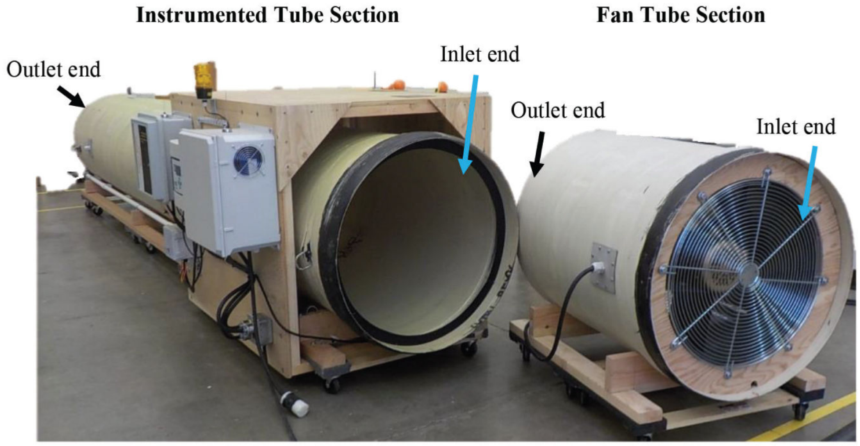

Figure 2 —.
Two-tube section of the Vent-Tube apparatus.

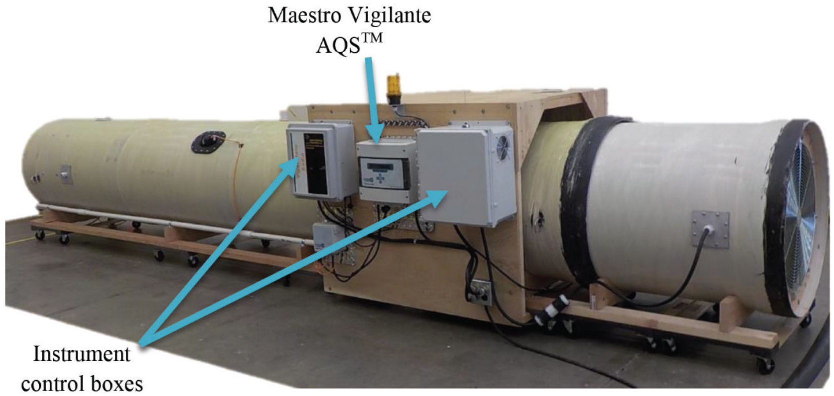

Figure 3 —.
Assembled Vent-Tube apparatus.

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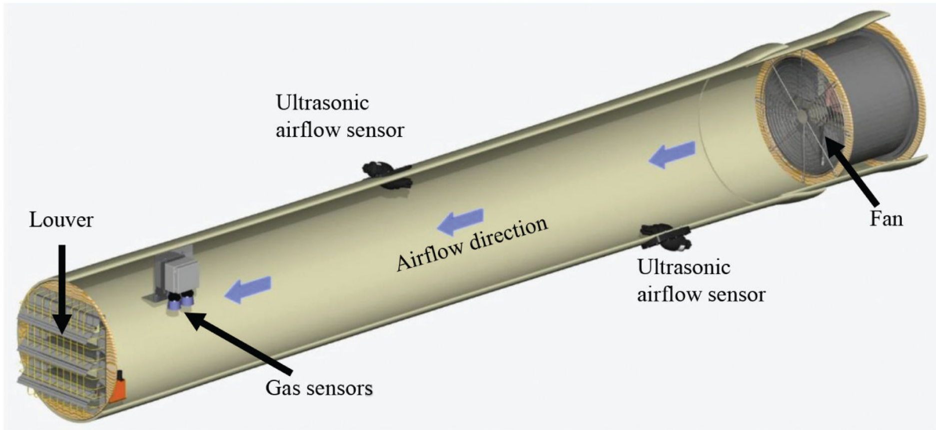

Figure 4 —.
Section view of the Vent-Tube apparatus.

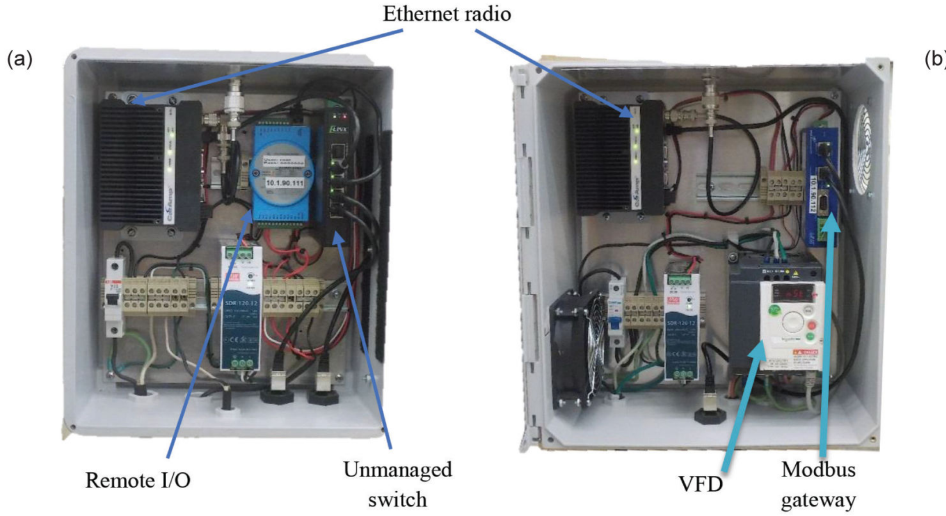

Figure 5 —.

Instrumentation control boxes: (a) slave radio is connected to the data acquisition unit and the louver controller through an unmanaged switch and (b) slave radio is connected to the VFD by a Modbus gateway.

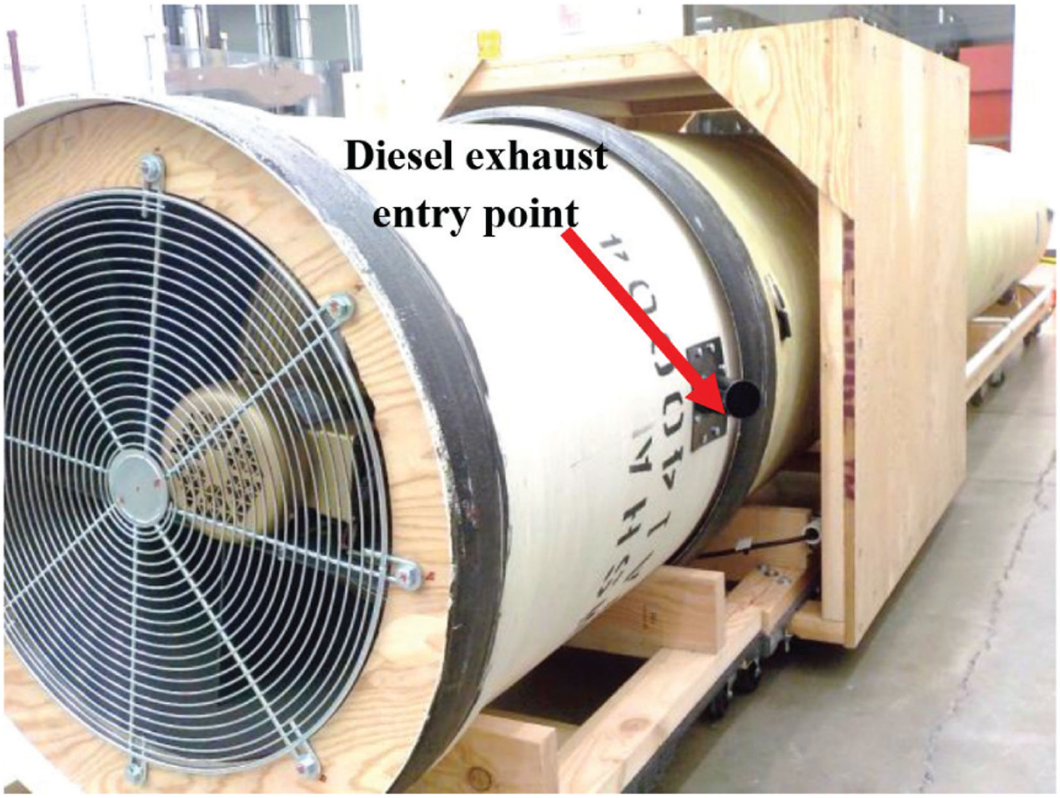

Figure 6 —.
Vent-Tube diesel exhaust entry point.

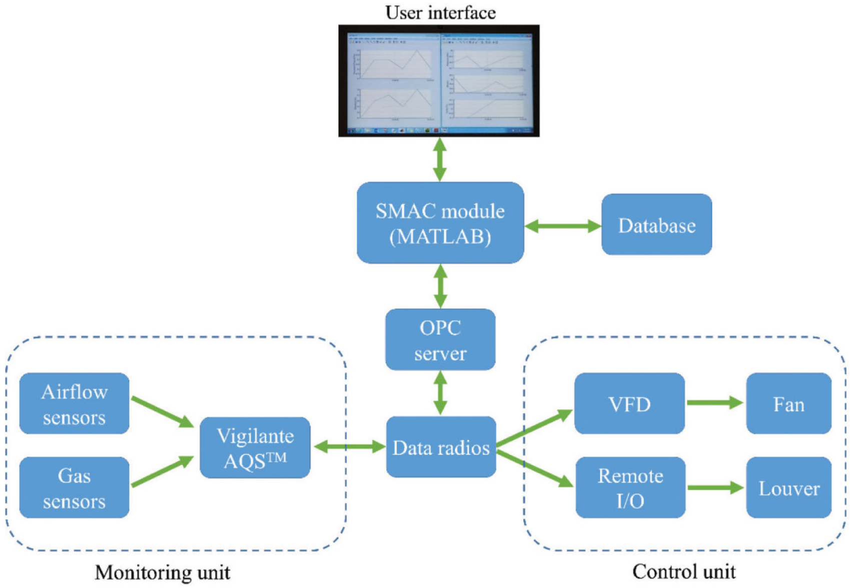

Figure 7 —.
Architecture of the SMAC system.