Using Real-Time Data Logging to Detect Unsafe Conditions and Safeguard Against Manhole Events

Dr. Mark Newton
Vice President, Engineering
Novinium, Inc.
Kent, WA USA
Mark.Newton@Novinium.com

I. Introduction

Manholes and vaults are subterranean confined spaces containing utility infrastructure vital to supporting the standards of life in today's societies. These spaces are harsh environments exposed to the elements, severe pollution from natural debit, vegetation, human trash, automobile fumes, acid rain and high concentrations of salt and fresh water. The infrastructure in the manholes regularly create micro-environments that are hostile or lethal to humans and capable of damaging or destroying the equipment and constructions contained within. Toxic gases are created through the breakdown and decomposition of materials used inside the networks of vaults as well as those introduced into the vaults i.e. the disposal of gasoline or other toxic chemicals. Often, the atmospheres inside these confined spaces are anaerobic or lacking in oxygen and polymers, metals and natural materials that decompose within, produce toxic and explosive gases. This issue is exacerbated by interconnections and leaks from adjoining structures as electrical manholes often cross sewer or natural gas pipes and leaks may occur between these spaces.

A "manhole event" is a term used to describe smoke, fire or an explosion in an underground structure such as a manhole, vault or service box. The event can originate within the structure itself or in a cable duct or pipe between structures. The most catastrophic type of events are explosions which can damage the inside and top of the structure, the road and can lift the manhole cover into the air. During these events, damage to the manhole as well as the surroundings of the manhole can be significant. There are thousands of manhole events that occur in North America each year and the frequency of events appear to be rising as electrical, gas and water infrastructure ages.

II. Background

Manhole events can arise due to a number of causes. In electrical manholes, events can be initiated by low impedance phase-to-phase fault or high impedance faults caused by contaminants in the ducts or manhole. Events also occur in gas and waste water vaults through small leaks or creation and pooling of methane.

An extremely common type of event is caused by the decomposition of electrical insulation in an aerobic environment and this produces flammable gases such as carbon monoxide (CO). Events can be created through both short and long processes, event producing environments typically develop in periods of seconds to weeks. Further, lacking a source of ignition these environments may remain for long periods before the event occurs. Alternatively these gases may leak into adjoining structures such as buildings, thereby causing health hazards. Other factors contributing to the generation of flammable gases include those from public disposal of combustible materials that find their way into manholes, or as a result of decaying organic material that has fallen or been washed into the vaults which in turn decompose and generate toxic gasses. As mentioned earlier, combustible gases can accumulate inside manholes as a result of gas line leaks or from sewage systems that are frequently routed through or near other underground structures.

In addition to manhole events, many other adverse environments may be present that are hazardous to humans and animals, these include flooding of the structures, equipment malfunctioning and overheating, and functional failure through the accumulation of debris, unauthorized access, damage from pest infestation or physical damage from vibration or wear.

Entries to these structures are rare and even the most conservative utilities only inspect the holes once every 5 years, with still others entering only when equipment or infrastructure requires service. Actively monitoring these spaces for gasses, temperature, water level, degradation, electrical discharge, movement, light or humidity, in real time and receiving actionable alarms in advance of events or failures, will allow service owners to take action before issues occur. Long-term, actively monitoring these spaces will facilitate development of preventative maintenance programs that provides for planned infrastructure refurbishment and replacement, while still being able to react quickly to unplanned issues prior to events occurring.

III. Active Monitoring Solutions

A ruggedized data logger for use inside manholes and other subterranean structures must be capable of being installed and remaining fully functional and calibrated in an unattended manhole for many years. The system needs to be able to sample and monitor from multiple sensors simultaneously and these sensors should cover the gamut of requirements to fulfil industry needs. In the most general terms, the types of sensors required can be grouped into:

- Gas concentration
- Physical properties i.e. temperature, RH, pressure, water level and fire
- Motion using multiple methods i.e. proximity, automated cameras, visible and thermal spectrums
- Electrical properties and discharge i.e. ultrasonic, RF, TEV and coupled discharge
- Equipment function i.e. valve and switch position
- Chemical properties i.e. water salinity or transformer oil contamination

The logger must remain functional during times when the manhole is flooded and during periods of power outages. The data should be stored internally as well as be transmitted in real-time, or as soon as possible to central locations where analytics can be performed to determine the current state of the underground structures. This information may be used as standalone data or integrated into a network map.

Any successful solution must also have the capability to self-test and report on its internal state. The system should be able to control infrastructure in safety critical environments i.e. controlling local equipment to shut down during a fire; as well as integrating with existing networks, safety equipment and solutions.

Figure 1 demonstrates a typical configuration of such a data logger.

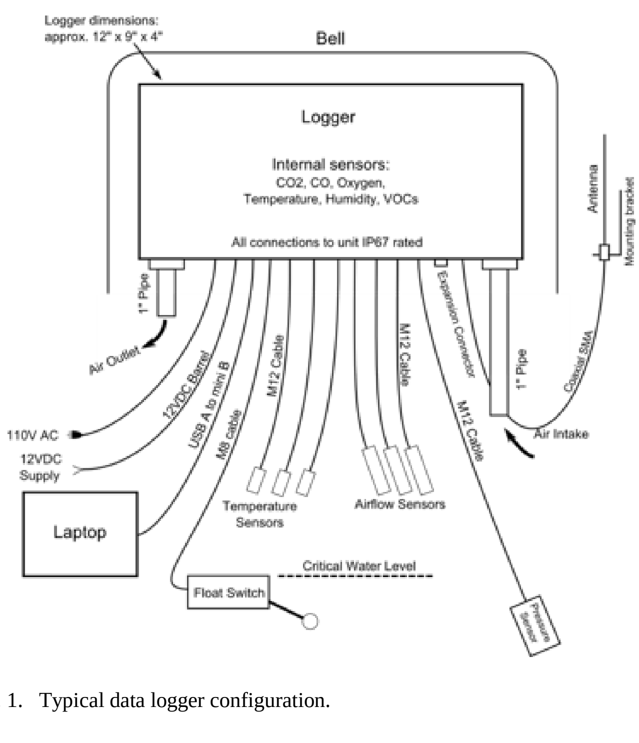

Fig. 1. Typical data logger configuration.

IV. The Novinium PreVent™ Solution

Novinium has spent the last two years developing a real-time ruggedized, very low maintenance data logger for use in subterranean confined spaces. The Patent Pending data logger (Figure 2) is capable of sampling and monitoring multiple sensors simultaneously, including many types of off the shelf devices (an example list is included in appendix A). Along with custom sensors, equipment control is also possible with this device utilizing the built-in expansion port. A typical sensor configuration includes sensors for H_2S (0-5% by volume), CO (0-30% by volume), Oxygen (0-25% by volume), Temperature (0°F to 140°F), Humidity (0-100% RH) and Volatile organic compounds (0-5%), and several external sensors, airflow sensors, temperature sensors, a float switch and a pressure sensor for water level.

The PreVent™ data logger was conceived with ruggedness, longevity and low maintenance at the heart of its design. The system comes standard mounted in a waterproof bell housing; this innovation protects the logger from contamination, debris or submersion; even when the manhole becomes completely flooded. All the electronics are coated to protect against humidity and other contaminants. The logger includes a self-heating mechanism to prevent condensation and fine particulate filtration to enhance the life of the sensitive gas sensing elements and electronics. All connections and fittings have a minimum IP67-rating and the logger has an expansion port to accommodate proprietary sensors, control technologies and capabilities that include digital and analog IO, UART, SPI, I2C and more.

Additionally the Novinium PreVent™ Smart System is equipped with an air sampling device; this feature was critical breakthrough that significantly enhanced the life and calibration of the sensors. The system hibernates between readings, both conserving power and preventing constant exposure to the "dirty" environment inside the manhole; it only samples air during a reading and is otherwise isolated from the environment. During a measurement the device will wake from hibernation, start a fan to draw an air sample from the bottom, middle or top of the manhole and then perform an analysis. The logger will then take a series of measurements and store the data locally, while simultaneously transmitting the information over a wired, Wi-Fi or cellular network. If the network is not available then the data is held in the "unsent" memory buffer until the connection is reestablished. Further, if the water level is close to, or above the lower rim of the bell, the system will shut down until the water recedes below the level of the logger.

Fig. 2. Front and bottom views of the PreVent™ Smart System data logger.

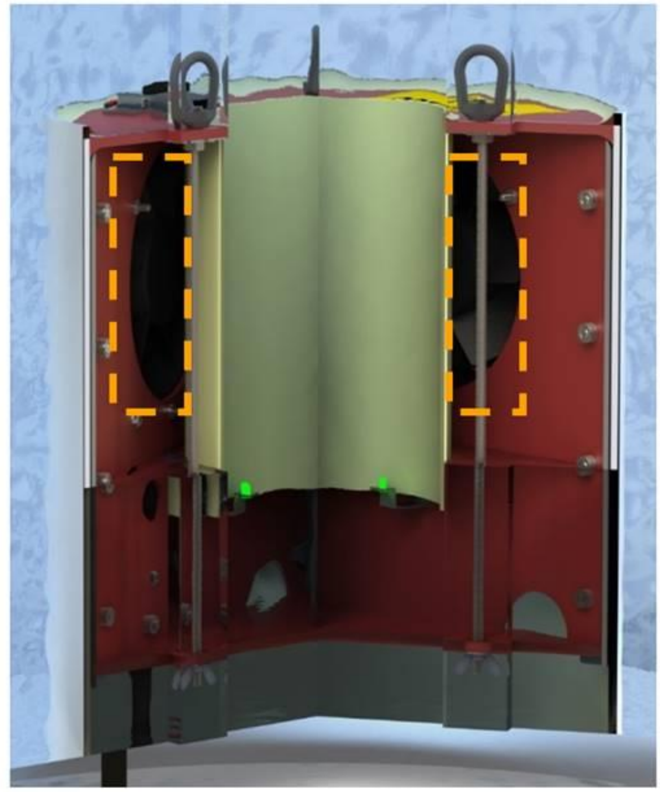

Fig. 3. Manhole event suppression system.

The PreVent™ system uploads data to a cloud via any of the networks mentioned, if no other type of connection is currently available in the underground network then an encrypted cellular GSM network connection is utilized to provide the data link. In the event that the data cannot be uploaded for some reason (i.e. a truck parked over manhole, or the GSM network is down etc.), then the logger stores the current and all subsequent data in non-volatile memory and waits until the network becomes available, after an upload confirmation is received the data is transferred to the local permanent memory.

The rate of logging is fully tailorable, PreVent™ is supplied with three standard log rates: normal, high, and extreme. The log intervals are fully customizable by the user though typically values are 10-120 minutes, 0.5-5 minutes, and 1-60 seconds. The log rate is chosen by the microcontroller based on whether any of the measured quantities are in their normal, high or extreme ranges and these ranges may be adjusted through baseline data from the logger or information provided by the manhole owner. Through sophisticated analytics, individual PreVent™ devices can "baseline" typical conditions observed in a manhole; this data is then used to set alarm and warning limits that are tailored to that specific location. The system can be powered from many sources including 110VAC or 12VDC, with power consumption ranging from 0.05 to 8 watts, with an average of ~1 watt. When within a manhole, a technician with appropriate security protocols has the ability to plug a laptop into the logger and download, troubleshoot, configure the logger and update the unit firmware.

Figure 3 shows the manhole event suppression system(s), a complimentary technology developed by Novinium to prevent the type of manhole events described in the introduction. When used in conjunction with the PreVent™ data logger the combined system provides an early warning and extends the response time available to address a manhole at risk from an event. If an event is imminent the logger will control the PreVent™ manhole event suppression system by setting the ventilation rate to maximum until the issue can be addressed.

The PreVent™ cloud, interface and analytics provide an easy to use visual dashboard. This secure, web-based system enables full control and management over all devices in a customer's network. Once system access is granted, a simple homepage shows the index of devices and status of each device with any "abnormal" occurrences highlighted. Drilling down into individual or networks of devices, the next page shows a detailed real-time display of all sensors and measurements from that single device or the devices joined in a network. Go even deeper by selecting any individual measurement, and this provides historical graphical data (including alarm limits) of each sensor as well as detailed analytics statistics to help baseline, characterize and predict any possible issues. The cloud further initiates event alerts in the form of emails, text messages or triggering control panel alerts. These are sent immediately upon the detection of readings outside of pre-set user-defined conditions. These alerts can include the presence of, or change in, the levels of explosive gases, temperature conditions, water levels, fire, or any other programmed parameters.

Further the data logger may be configured to instruct the system to execute a pre-programed routine if required to test itself or other equipment in the vault. The data logger may be connected to neighboring data loggers or manhole event suppression systems through either a direct connection or communication protocols such as SCADA, IEC 61850, IEEE 802.11, IEEE 802.16, Bluetooth, Wi-Fi, cellular networks, and even satellite networks.

The data from the smart system can also be used to determine how to optimize and predict performance of other manholes connected to the same physical network. Special instructions can be communicated back to the centralized computing system to optimize performance and/or change the behavior of the manhole event suppression systems connected to that network of manholes.

V. Available Sensor Types

The following sensor types are available with the PreVent™ Data Logger:

- Accelerometer
- Cable temperature sensor
- Camera to be activated based on an event or trigger
- Carbon dioxide concentration sensor
- Carbon monoxide concentration sensor
- Conductivity of water sensor
- Current sensor
- GPS
- Hydrocarbon sensor to measure a concentration of gasses (e.g., propane, octane, etc.)
- Hydrogen concentration sensor
- Hydrogen Sulfide
- Infrared (“IR”) sensor to detect relative temperature differences of equipment and system components
- Light sensor to detect changes in ambient light conditions and indicate when the manhole cover is lifted or opened
- Methane sensor
- Motion Sensor
- Oxygen concentration sensor
- Partial discharge sensor
- Particulates / Opacity sensor
- Pressure sensor to measure the atmospheric pressure
- Radio frequency (“RF”) signal sensor for an electrical discharge or partial discharge activity
- Radon sensor
- Relative humidity sensor
- Salinity of water sensor
- Stray voltage detection sensor
- System voltage sensor to monitor for voltage spikes and voltage transients
- Transient Earth Voltage (TEV) sensor to monitor for an electrical discharge or partial discharge transients
- Ultrasonic to measure electrical discharge or partial discharge activity
- Ultraviolet (“UV”) sensor to detect the light emitted in the ultraviolet spectrum from corona discharge
- Vault ambient temperature sensor
- Vault/conduit air flow sensor
- Vibration sensor
- Water flowrate sensor
- Water level sensor