

Wireless Gas Sensing in South African Underground Platinum Mines

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Abstract— Approximately 70% of South African mines are classified as fiery, where methane gas potentially could cause explosions. The number of flammable gas reports and accidents are increasing steadily for both gold and platinum mines. However, there is less awareness of the hazards of methane in hard rock mines (gold and platinum) than in coal mines. Currently, there is no wireless real-time gas sensing system used in South African hard rock mines. The main objective of this work is to investigate the possibility of using a wireless gas detector called GS01 in underground mines. Several experiments have been conducted to evaluate the GS01 performance, accuracy and the ability to communicate in underground mines. The results demonstrate the suitability of using GS01 in such harsh environments. A second motivation for the work was to evaluate the performance of wireless communication using different frequencies.

Keywords—gas sensing, underground mines, ISA100.11a, GS01

I. INTRODUCTION

There are various sensing needs in underground mining resulting from the mining process and environment to the state-of-the-rock mass. Gas sensing is needed for safety reasons during the mining process when the face advances, as this can result in rock bursts that can maim or kill miners in the vicinity. Gas sensing is also needed in the mining environment near the face as explosions due to inflammable gas may occur.

There is currently no real-time monitoring of gas in South African mines. Gas is monitored by handheld devices carried by humans tasked from time-to-time to check for specific gases. Approximately 70% of South African mines are classified as “fiery” where methane can cause explosions and in mechanized mines carbon monoxide is a problem.

Combustible gases are reported from hard rock and other

non-coal mining operations all around the world, and occur in numerous strata and ores. Methane is the predominant gas, although often associated with other hydrocarbons and hydrogen. The geological origins of methane can be determined by isotopic analysis of the carbon and hydrogen in the methane, with the carbon isotope ^{13}C the main indicator. South Africa has combustible gases in almost all gold and platinum mines, as well as in kimberlite pipes associated with diamond mines.

Gold mines have more ignition-related accidents, whereas the platinum mines have face outbursts during drilling, usually without ignition.

There is a general lack of awareness of the hazards of methane in mines, with only four mines considering combustible gases to be a problem. It is likely that methane is regularly emitted from strata but the normal ventilation is sufficient to control it. These factors, and the number of accidents involving ventilation and gas testing, show this lack of awareness.

The objectives of this work were to investigate how to adapt novel gas sensing technology developed by SINTEF [1] and GasSecure [2] for the oil and gas sector to the mining sector in South Africa. This gas detector falls in the category of infrared sensors. It is the first wireless infrared hydrocarbon gas detector to operate on battery power as well as with high reliability and low power consumption. Furthermore, its optical design guarantees high signal stability, no interference from environmental changes and no need for recalibration. This gas detector will only be tested for its underground operation with regards to methane sensing and for its wireless data transfer capability.

Section II provides an overview of the state-of-the-art for gas sensors as well as information on gas detectors currently used in the South African mining industry. A brief description

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of the gas detector and its communication architecture is given in Section III. The field tests and results are elaborated in Section IV. Section V elaborates on the comparison between different frequencies and finally section VI concludes the work.

II. RELATED WORK

The underground mines have two main structures: tunnel and room-pillar area. The latter can be viewed as a big room with pillars randomly deployed to support the ceiling. Most of the existing work has been done mainly in the tunnel area such as [3-7]. On the other hand, some work, for example [8, 9], has been aimed at in the room-pillar area. Moreover, the existing work has been done in an area of 5m height, where the working area in the platinum mines in South Africa is less than 1.2m as shown in Fig. 6 and Fig. 7.

Wireless real-time gas sensing is in its infancy. Most commonly either handheld devices or devices that are physically mounted onto walls and machines are used in South African mines. Typically, these mounted gas detectors may continuously transmit gas data through wired communication systems to the surface, issue a local alarm, or log data for subsequent analysis.

A. Gas sensing technologies

Gas sensing technologies come in different flavours. Infrared-based solutions offer great detection-speed improvements over semiconductor or catalytic solutions. These systems are currently the preferred method for mine-gas monitoring [11]. Recent products in industry include state-of-the-art infrared Axetris gas sensors manufactured in Switzerland [12]. Most of these infrared gas detectors are point infrared detectors, that is, they provide gas concentration measurements at the points where they are located.

Another technique, the open-path infrared detectors, allows monitoring along the beam emitted by the devices, therefore allowing remote gas sensing. The difference with these systems is that the infrared transmitter and receivers are separated by distances of up to 200 m, thus allowing remote gas sensing over long distances. The usage of such systems has not been widely adopted by the mining industry because the obstructions caused by the pillars in mine galleries might prevent optimal operation.

B. Gas detectors used in the South African mining industry

A number of infrared gas detectors (fixed and handheld) are available in industry from a number of industry leaders, such as Trolex [13], RKI [14] and General Monitors [15]. A small selection of these detectors is presented in TABLE I.

The handheld detectors, in particular, are beneficial for miners as they can directly assess gas concentration levels in their immediate proximity. By creating a wireless network with these devices as mobile nodes, real-time levels for gas concentration at different locations in the mines can be aggregated to form a map of gas concentration levels. However, no such network currently exists underground. Gas detection equipment used on South African platinum mines is provided in TABLE II.

TABLE I. INFRARED GAS DETECTORS

Model	Positioning	Gas Type
Trolex TX6363	Fixed	Methane and carbon dioxide. (Support for more gases through additional plug-in modules).
RKI Eagle 2	Handheld	Methane and carbon dioxide. (Support for more gases through additional plug-in modules).
General Monitors IR400	Fixed (Support for HART, Modbus)	Ethylene
General Monitors IR5500	Fixed (Support for HART, Modbus)	Methane and propane
Open Path		

In the normal mining situation, the detectors are calibrated for methane using standard methane calibration gas mixtures of for example 1.4% or 2.5%. When other hydrocarbons are present the readout could be adjusted by a correction factor, or the detectors could be calibrated for the most common gas. Suppliers and manufactures of detectors have a range of correction factors for individual gases. The gas emissions in underground mines are normally a mixture containing various gases. For a mixture of gases the lower explosion Level (LEL) of the mixture must first be calculated, and the correction factor is then assumed to be the same as an equivalent gas with a similar LEL to the mixture. This requires obtaining a complete list of correction factors for a range of gases from the manufacturer or supplier for specific detectors.

TABLE II. GAS DETECTION INSTRUMENTATION ON PLATINUM MINES

NAME	TYPE / COMMENTS
Gastech S006 Methanometers	Spot Measurements
HC 002 Methanometers	Continuous Monitors
Gastech, Tri-Tector, CH ₄ , CO and O ₂ Monitor	Used on Cap Lamps
Gastech CO Monitor	Fire Patrol
Logica CO + CH ₄ Monitors	Continuous Monitors
G D I Duel CO + CH ₄ Monitors	Continuous Monitors
Brogas S006 Methanometers	Spot Measurements
G F G Protectors	Vent. Department
Tox Alarm CO Monitors	Fire Patrol
Flamalarm	Cap Lamps
Gaswatch	Cap Lamps
Board MSA Methanometers	Spot Measurements

III. GS01 WIRELESS INFRARED HYDROCARBON GAS DETECTOR

A. The detector

The GS01, shown in Fig. 1, is developed by GasSecure [2]. To the best of our knowledge, GS01 is the first wireless infrared hydrocarbon gas detector to operate on battery power. It has a battery life-time of more than two years. The GS01 is based on MEMS technology to achieve high reliability and low power consumption. The novel optical design guarantees high signal stability, no interference from environmental changes and no need for recalibration. The wireless transmit power of the GS01 is 10mW. The sensor's specifications can be found at [16].



Fig. 1. The GS01 Wireless Infrared Hydrocarbon Gas Detector. Battery compartment to the left, sealed electronics housing in the middle and measurement volume to the right, protected with a weather protection. Antenna on the top, and mounting foot in the bottom.

Natural gas (mainly consisting of hydrocarbons) contains typically of 60% - 90% methane, 5% - 9% ethane, 3% - 18% propane, in addition to some butane, hydrogen sulphide (H₂S), and some other gases. Methane is lighter than air; ethane has approximately the same density, while butane and propane are heavier than air.

The sensor has been developed for detection of hydrocarbons from 0% to at least 100% of the lower explosion limit (LEL). In air, the explosion limits are provided in TABLE III:

TABLE III. GAS EXPLOSION LIMITS IN AIR

Gas	Lower Explosion Limit (LEL)	Upper Explosion Limit
Methane	5%	14%
Ethane	3%	13%
Propane	2%	10%
Butane	1.9%	9%

In any air mixture with concentrations between LEL and the UEL, the mixture may ignite and explode. The GS01 has a detection limit of 4% of LEL, meaning a detection limit for methane at $4\% \times \text{LEL} = 4\% \times 5\% = 0.2\%$ methane, and is extremely well suited to avoid gas explosions.

B. The communication architecture

The wireless communication in GS01 is based on the ISA100.11a standard. This supports multihop functionality – a property that is assumed to be important in the challenging conditions found underground. The wired gateway contains a Modbus server. The sampled values can thus be investigated using any available Modbus client. This simple architecture is shown in Fig. 2.

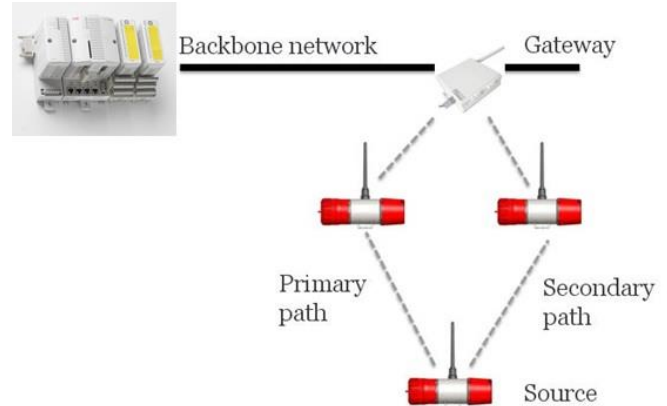


Fig. 2. The communication architecture

The results reported below refer only to a single detector, i.e. no multihop functionality was tested. Verifying the performance of the multihop capability of the detector underground remains to be done.

IV. GS01 FIELD TESTS

A. Response time

The aim of this test was to verify that the response time of the GS01 gas detector is acceptable for operation in mining environments. The specification of the detector is that it will take no more than 7 s from when gas enters the measurement volume until the gas is registered in the control room application.

In order to test the detector's response time, it was placed in a sealed plastic bag with its weather cap on. The bag was emptied for air. A container of methane of 50%LEL was connected via a 30cm hose to the emptied plastic bag. The flow of gas from the container was controlled manually, allowing the gas to fill the plastic bag and eventually fill the measurement volume of the detector inside the weather protection. A data logger was connected to the gateway. The time elapsed from the opening of the valve until the gas alarm was registered at the logger was noted manually. In addition, the data logger stored the development of the gas concentration measured in LEL. The test was repeated three times.

Fig. 3 shows the development of the concentration as a function of elapsed time from the opening of the valve for all the three experiments. A few points are worth noticing. First, gas was registered in less than 6 s. This is reasonable and suggests that the detector is sufficiently responsive to be used in mining operation. Second, the steady state concentration levels of the detectors vary from 25 to 35 %LEL. This apparent

error is caused by the fact that the plastic bag was not completely evacuated when the gas was applied, reflecting the air / test gas volume fraction. This led to the significant variations in gas exposure recorded.

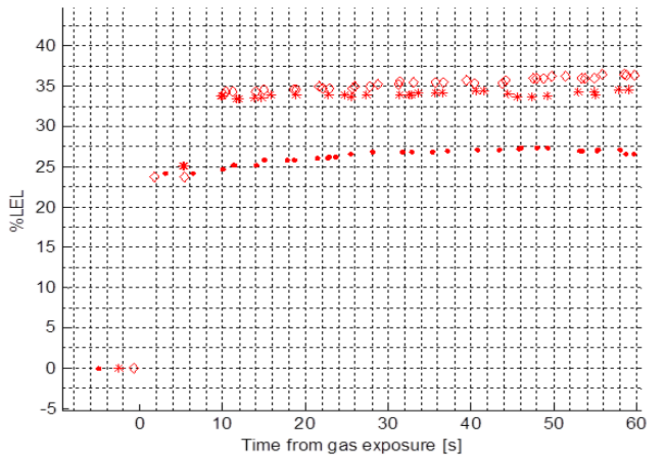


Fig. 3. GS01 successive measurements of LEL

B. Similar mine environment

To test the GS01 under similar temperature and humidity of the underground mine, the GS01 has been tested using a TestEquity temperature chamber [17]. The chamber is shown in Fig. 4.



Fig. 4. Temperature chamber

The tests were performed at GasSecure's test facility in Oslo. A GS01, a humidity sensor and a water-filled bowl were placed in an air tight plastic bag. A hose was connected to the plastic bag and the end of the hose was placed at the bottom of the bowl. The bag was then placed in a temperature chamber set to 40 °C. A data logger was connected to the gateway.

The temperature chamber remained switched on during the night in order for the detector to reach thermal equilibrium. The relative humidity (RH) was 90%. After thermal equilibrium and high humidity was achieved, propane test gas (0.415vol% in synthetic air) was applied to the hose at a slow flow rate. The test gas was bubbled through water in order to be humidified.

Fig. 5 shows the GS01 measurements under humid conditions. Before the gas is applied, the relative humidity is 90%, and GS01's zero point is shifted to -2%LEL. When the

bag is opened, and the propane gas and the water vapour are ventilated away at time 09:19, the zero point level is back to ~0%LEL. The relative humidity at this time was 40%. Due to cross-sensitivity to water vapour, the zero point when humidity changes from 90% to 40% RH is shifted by -2%LEL methane equivalents.

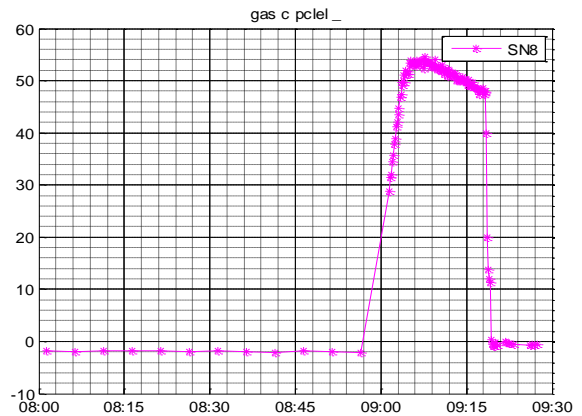


Fig. 5. GS01 (SN8) at 40 °C and 90%RH is exposed to humid propane gas. %LEL is plotted against clock time (HH:MM).

As the propane gas is not replacing the humid air in the measurement volume, just mixing with it, its final concentration is not known, so the measurement shows that the detector is still able to detect gas in humid conditions, but the accuracy is not proven.

The test shows that humid, non-condensing conditions reduces zero-point level of the detector by 2%LEL methane equivalents, if the relative humidity is increased from 40% to 90%.

It is expected that gas readings also will be reduced by a few %LEL due to the cross-sensitivity to water vapour.

C. GS01 in mines

The aim of the mine testing was to establish if the operating environment of the mine posed particular problems to the communication part of the GS01. The detector is based on the ISA100.11a standard [18]. Being based on 2.4 GHz it was assumed that the harsh conditions could cause serious disruption to the wireless exchange of information.

The ISA100.11a standard is based on the IEEE 802.15.4 physical layer. This is the well-known basis of the ZigBee standard. Contrary to ZigBee, but similarly to WirelessHART, it has a strict time division access scheme. This supports both low power consumption and multihop capability, both of which are essential in battery powered industrial applications.

The ability to form multihop networks, i.e. that a radio message can pass through several relay nodes before reaching its final destination, is thought to be crucial to the operation underground. Here the physical limitations are severe and there will most likely be several radio hops between the most remote nodes and the gateway. However, in this particular test, the multihop capability was not tested.

The tests were conducted in the face area (Fig. 6) and back area (Fig. 7). The face area is the active area, where rock containing the reef is removed. A further 6 m behind the active face is the so-called “back area” with some form of permanent support which could be either steel or wooden support units. The length of these areas varies from 20 m to 30 m with a height of less than 1.2 m.



Fig. 6. Face area



Fig. 7. Back area

One GS01 and one gateway were taken down into the platinum mine test site in Rustenburg. A laptop was used for logging the parameters of received signal strength indicator (RSSI) and packet error rate (PER). These two parameters were recorded as a function of the distance between the gateway and the GS01.

The gateway was placed at the starting edge of the face area with the gateway connected to the laptop. Initially, GS01 was located at 5 m from the gateway. The GSAP (Gateway Service Access Point) interface was used to log the RSSI and PER. The GS01 was placed at varying distances from the gateway at step increments of 5 m. At each point the RSSI and PER were recorded. At each distance the measurements were taken for at least 10 minutes to allow the PER and RSSI estimates to converge to its steady state values. Because of the limited size of the face area, the maximum measured distance was only 20 m.

The measurements were repeated in the back area as well, where the GS01 was located in NLOS (non-line of sight) with

the gateway. In the back area, the test could be conducted up to 30 m.

Fig. 8 shows the observed RSSI as a function of distance for the GS01 in the face area and the back area. Although the GS01 performed better in the face area, its performance in the back area is satisfactory. An important observation from this figure is that both curves exhibit an almost monotonically decreasing RSSI with increasing separation.

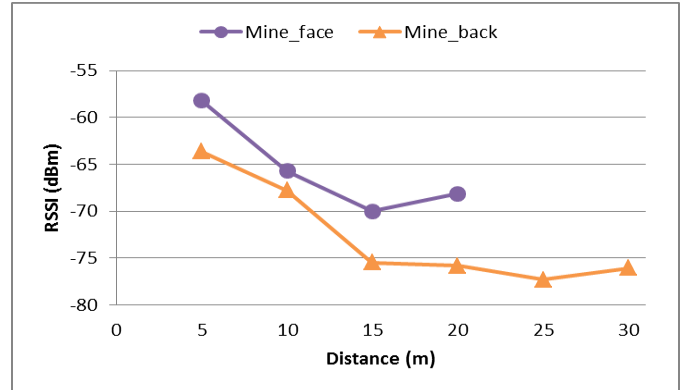


Fig. 8. RSSI at different distances for the GS01

In a multipath signal environment, signal peaks and nulls could exist. The phenomenon of nulls, known as static fading, is mitigated by using technologies like ISA100.11a or wirelessHART. This is because they both use mesh networking and frequency hopping. The former technique allows the signal to choose the best set of nodes to pass through by which to relay the data packets. The latter avoids fades by utilising a wide range of frequencies where the fading characteristics are different.

Fig. 9 confirms the good performance of the GS01 in both the face and the back area. This figure shows that the PER in the face area is equal to zero in most of the distances, while it has a very low value in the back area except at 30 m, which has the value of 18.9%. However, in order to get a good estimate of PER, a considerable number of samples is necessary, which requires conducting the test for longer durations. On the other hand, placing the GS01 in a location that is very close to the LOS with the gateway could have a high impact on enhancing the communication quality of the GS01.

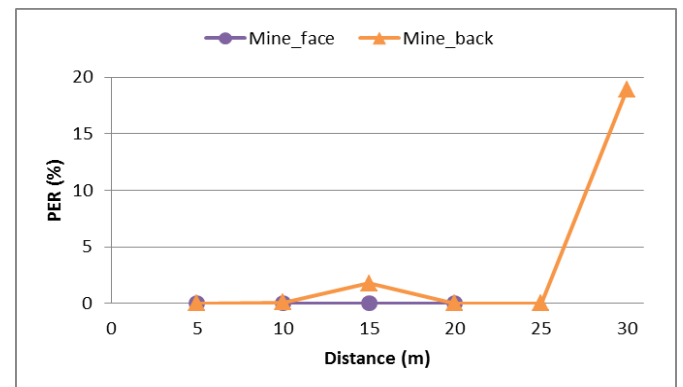


Fig. 9. PER at different distances for the GS01

V. ALTERNATIVE FREQUENCIES

The ISA100.11a standard on which the GS01 is based operates in the 2.4GHz range. In fact, most commercially available wireless sensor networks such as WirelessHART, ZigBee and others are designed primarily for use in this band. However, conditions in hard rock mines are special with narrow passages and very low headroom, particularly in the face area. It therefore seemed appropriate to evaluate the RF performance at alternative frequencies.

Two other frequencies were considered, 433MHz and 868MHz. We measured the RSSI as function of distance using an FSH3 handheld spectrum analyser from Rhode and Schwartz. Fig. 10 summarises the results for one test in the face area.

The three different units transmitting at the different frequencies also transmitted at different power. In the plot below this has been normalised in order to facilitate a good comparison of the frequency dependent attenuation.

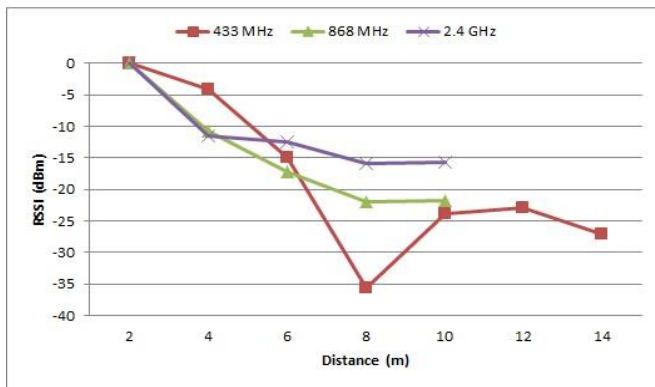


Fig. 10. RSSI for the three frequencies; 433 MHz, 868 MHz and 2.4 GHz

It is hard to make clear conclusions based on these results. The most striking observation is that the attenuation at 8m separation for 433MHz has a deep fade. Given that the wavelength at low frequency is longer than at high frequency, one might have expected fading problems to be a more serious problem at 2.4GHz. This observation therefore seems to contradict conventional wisdom. On the other hand, this is the result of a single test. More tests, with different local geometrical variations, could shed more light on the question.

The second, equally interesting, observation is that as the separation increases, the 2.4GHz version seems to have the best performance. Again, this is contrary to what is usually observed above ground, and more testing is needed for final verification.

VI. CONCLUSION AND FURTHER WORK

The principal conclusion from this study is that the GS01 detector has a performance, in terms of speed, accuracy and communication capacity, that is suitable for measurement in

underground mining operations. It has also shown that the detector is able to cope with the high temperature and humidity levels usually experienced in hard rock mines. The testing in this study was performed using a single detector. The increase in PER at 30 m separation in the back area suggests that there is a potential performance gain if the mesh capability of the technology is utilised. A new in depth study will therefore use more detectors and study the communication performance using different network topologies.

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