NEW WIRELESS IR GAS DETECTOR FOR SAFETY INTERGRITY LEVEL 2 APPLICATIONS USING MEMS TECHNOLOGY

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ABSTRACT

Infrared hydrocarbon gas detectors are essential for safety at oil and gas installations, but cables for power and communication complicate installation. A detector with a low-power optical design based on a Microelectromechanical system (MEMS) gives several years of reliable battery operation. This detector communicates wirelessly. The main challenges with safe wireless communication are to guarantee a short response time and to immediately detect loss of contact with detectors. This detector has proven to have reliable operation in various challenging environments. Test results from one year offshore operation in the North Sea are reported.

INTRODUCTION

Reliable and fast detection of hydrocarbon gas leaks is important for safety in the petroleum industry. Infrared absorption measurement is a widely used and approved method. Point detectors are installed at strategic locations and measure the gas concentration of the air flowing naturally into the detector's measurement volume. The measurement itself is not particularly challenging from a spectroscopist's point of view, since explosive mixtures of hydrocarbons in air typically absorbs more than 10% of the power in a wide spectral band using a pathlength of only 10cm. However, the real challenge lies in designing a reliable, practical, and not too expensive instrument also satisfying the following requirement: No recalibration shall be necessary during a lifetime of up to 20 years, in a wide operating temperature range and harsh environment (1).

There are also strict requirements on the probabilities for false negatives (non-detection) and false positives (false alarms). A few commercially available gas detectors have demonstrated that they satisfy the requirements above. However, the energy consumption is on the order of 3W to 5W, and as much as 80% of the detection system cost may come from installing cables for power supply and communication. Therefore, there is a demand for battery operated, wireless detectors.

GasSecure of Norway has developed a wireless, infrared based gas detector satisfying the above requirements of high reliability with fast response time and no recalibration. The detector has proven performance in challenging climates from arctic to tropical. Typical battery lifetime is two years with continuous monitoring.

FIGURE 1. THE MEMS-BASED INFRARED GAS DETECTOR GS01 WITH BATTERY COMPARTMENT TO THE RIGHT, WEATHER PROTECTION TO THE LEFT, ELECTRONICS AND SPECTROMETER IN THE STEEL HOUSING AND ANTENNA ON TOP.

ENERGY-EFFICIENT SENSOR SYSTEM

Several techniques are implemented for reducing energy consumption from watts to milliwatts, and three of the most important are:

1. The infrared sensor works in combination with an ultrasonic sensor allowing the more energy consuming infrared sensor to spend much of its time in a standby state.
2. The wake-up time of the infrared sensor is short, and a complete measurement takes only 0.5 second.
3. A compact and simple optical design makes efficient use of the light from a small source.

By default the infrared sensor will execute an optical measurement every third second providing reliable infrared gas concentration measurements. This main loop is represented as the solid line in FIGURE 2. In addition to the infrared sensor, an ultrasonic sensor is included to continuously measure the air composition by measuring the speed of sound by ultrasonic pulses.

The speed of sound in a gas mixture depends on the average molecular weight and the temperature. Two piezo-electric ultrasonic transducers are used to send a pulse through the measuring volume (inside weather protection) and receive the reflected pulse about 0.4

milliseconds later. The actual time delay is measured with accuracy better than 100ns. A small, fast, and accurate temperature sensor (NTC) resides in the same volume. When temperature is corrected for, any significant remaining change in time-of-flight is assumed to be due to an increased concentration of hydrocarbons in air, unless proven otherwise by the optical sensor.

The dashed lines in FIGURE 2 represent an option to skip the optical measurement and use the previous measurement value, provided that the ultrasonic measurements prove there is no significant change in the air composition (2). Every fifth minute the optical measurement will execute, to perform diagnostics on the optical sensor, regardless of the ultrasonic measurement.

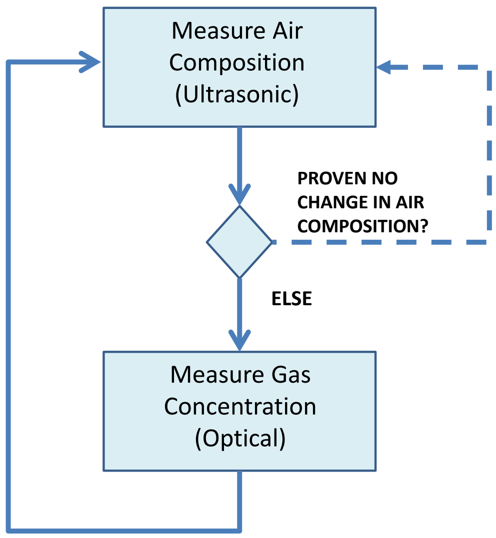
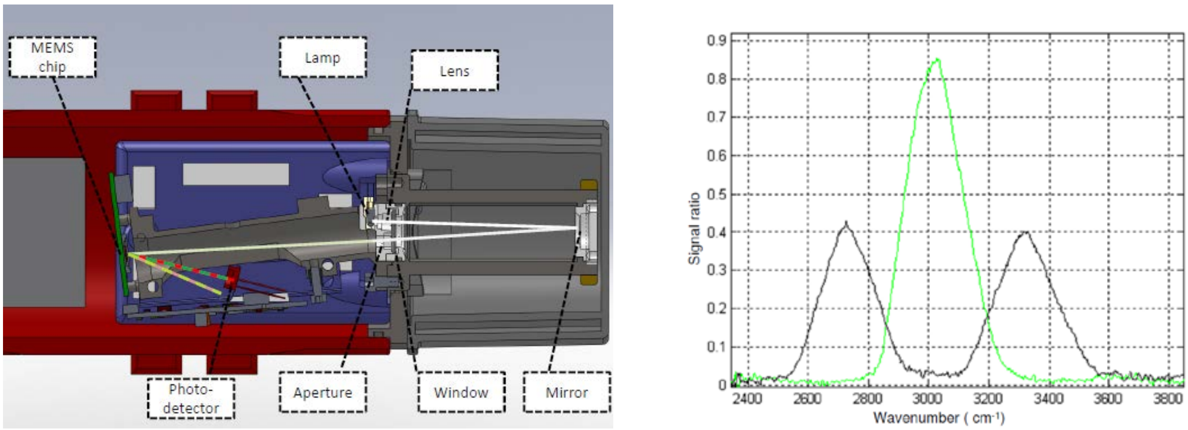


FIGURE 2. FLOWCHART SHOWING THE OPERATIONAL PRINCIPLE OF THE TWO SENSORS IN THE GAS DETECTOR.

INFRARED SENSOR DESIGN

For the two-sensor combination to work, the infrared sensor must be able to shift from standby mode to active mode in milliseconds and produce reliable output within one second, before it goes back to standby. It must also be energy-efficient. It is found that such an infrared sensor could be made based on a voltage-controlled holographic MEMS chip (3, 4) that can switch between measurement and reference wavelength bands. A complete measurement takes 0.5s, and is completely self-contained, with no additional filtering. Each measurement represents the actual gas concentration in the cell. FIGURE 3(a) shows a drawing of the infrared sensor. The core of the spectrometer system is a micro-electromechanical system (MEMS) that disperses, focuses, and modulates the incident light. By applying a control voltage to the MEMS chip, the filter switches between the measurement state (central absorption band) and the reference state (double sideband), shown in FIGURE 3(b), at a frequency of 1kHz. The filter shapes are designed to give approximately equal power in the two states when there is no gas present, and the difference signal can be measured with greater accuracy than the signal levels corresponding to each filter state separately. The same light source and detector are used for the gas and reference measurements.



(a) (b)

FIGURE 3. THE MEMS-BASED INFRARED GAS SENSOR.

(a) OPTOMECHANICAL DESIGN SHOWING THE MAIN OPTICAL COMPONENTS, THE BEAM OF BROAD BAND LIGHT (WHITE LINE), AND THE FILTERED AND MODULATED BEAM (RED AND GREEN DASHED LINE).

(b) THE FILTER FUNCTIONS USED FOR METHANE DETECTION, CORRESPONDING TO THE TWO STATES OF THE MEMS (GREEN AND BLACK), MEASURED USING AN EXTERNAL INTERFEROMETER.

The energy consumed during a single gas concentration measurement has been measured to 140mJ. Approximately two thirds is required by the light source, and one third by the microcontroller and electronic circuitry. If triggered every minute, the average power becomes 2.33mW. This allows several years of operation on a lithium-thionyl chloride battery pack with a volume less than 250cm3. Because a complete measurement takes less than half a second, the response time is dominated by the measuring frequency and the diffusion of gas into the measuring volume through the weather protection. The weather protection is designed to protect against the environment but will allow gas to freely flow through, there are no filters or humidity absorbers.

COMPARISON WITH NON-DISPERSIVE INFRARED GAS DETECTORS

Unlike a laboratory spectrophotometer that can be manually recalibrated as a part of the measurement procedure by subtracting the dark signal and normalizing the response of the photo-detector(s), an infrared gas sensor must rely on built-in mechanisms to compensate for drifting source intensities, detector response, and various other error sources. The simplest non-dispersive infrared (NDIR) gas sensors have only one wavelength channel and are considered unreliable for safety applications. More advanced detectors use a combination of reference wavelengths and/or reference light paths to achieve self-calibration. A typical configuration of a double-compensated detector uses four measurements to calculate gas concentration (two wavelengths combined with two detectors measuring internal and external light paths). Ideally this method eliminates error sources such as drifting source intensities or dirty optical windows. When concerned about energy consumption, there are some disadvantages with the double-compensated system as described: Rapid infrared source modulation is required, and energy is lost in the heating and cooling cycle. There is also an arrangement of beam splitters that result in lost light. In order to achieve stable measurements there must be a certain degree of thermal equilibrium in the system. This often requires start-up times from tens of seconds up to several minutes, and excludes intermittent operation with short duty cycles.

SAFE WIRELESS COMMUNICATION

Energy constraints for battery powered instruments limits, the rate at which the instruments can report process values. For most process monitoring applications, this is not a major obstacle as the process values in question tend to change relatively slowly. For safety applications, the picture is somewhat different. For most safety applications continuous monitoring is necessary and a short latency (response time) needs to be guaranteed if a safety critical situation arises. However, the average bandwidth requirement is modest. Thus the primary difficulty in designing a wireless safety system is having a guaranteed short latency while not depleting the batteries. In addition, full control of all network message traffic is required, and loss of contact with a device must be identified immediately.

The wireless gas detector is intended for monitoring applications as well as for safety applications. For safety applications, the communication with the controller needs to meet reliability requirements according to Safety Integrity Level 2 (SIL 2) guidelines as described in IEC 61508 Ed.2.0 (5).

NETWORK TOPOLOGY

Wireless communication from the gas detectors is based on the standard protocol ISA100.11a (6). The gas detectors may be installed in full mesh topology, star topology or in a combination of the two topologies. It is possible to provide redundant paths between the controller and wireless gas detectors via redundant field access points, and to provide multiple communication paths from the wireless gas detectors to multiple redundant field access points. The ISA100.11a standard defines the many basic functions which improve data transfer reliability in communication. If the normal path used by a gas detector is obstructed or becomes unavailable, the gas detector will transmit its data along a redundant path. This leads to immensely stable and predictable networks.

The deployment of a wireless gas detector network is simple. The gas detectors are placed in their desired locations and powered on. Subsequently, each gas detector will spend some initial time conferring with its neighbors, obtaining an image of the network and the available paths to the network access point. The network information will include not only what neighbors are available for communication, but also the associated quality of each individual link. The aggregated information is stored in the network manager, which is responsible for scheduling communication opportunities.

Once the network has stabilized, the traffic intensity drops. However, the gas detectors will continue to update their neighbor link information, including the possible removal or addition of gas detectors. In this way the network becomes adaptable to changes in the topology or of the environment.

SAFETY MECHANISMS IN WIRELESS NETWORKS

For safe communication satisfying IEC 61508 SIL 2 level, four error handling mechanisms must be supported:

- sequence numbering
- timeout in the absence of response
- device code name
- data consistency checking

The purpose of these mechanisms is to detect failures of the safety device in terms of packet loss, unacceptable network delay, bit errors, replay attacks, etc.

Several options exist for implementing the four required safety features. One approach is to base the product on a certified implementation of an open safety protocol. PROFIsafe over PROFInet (7) and ISA100.11a has been chosen due to the widespread use of the former in process control applications (8). PROFIsafe executes the task of safe communication between host and field device. It can target safety function up to SIL3. All the communication devices between the field device (gas detector) and the host (safety controller) are considered to be part of a black channel.

Upon a request packet from the safety controller, the gas detector needs to respond to that packet, containing the four above-mentioned mechanisms, within the process safety time. Process safety time is normally set to 60 seconds for gas detection systems. If the device does not respond before the safety time elapses, the device is marked as unavailable in the control system. It is fundamental to the operation of all safety systems that the exchange of safe packets is initiated by the controller and that there is a one-to-one correspondence between the packet sent and the packet received. Once the controller receives a response, a new request can be issued.

In order to fulfill the requirement of fast response time in a gas detection system, there needs to be opportunities to send uplink packets approximately once every two seconds. The gas detector will therefore, during setup, request that bandwidth is set aside for this uplink transmission rate. Normally responses are delayed on purpose to save battery, and the transmit opportunity is most often not used by the gas detector. However, the fact that bandwidth has been reserved ensures that the gas detector can respond immediately if a gas concentration is measured (9). Thus, most uplink packets will be safe responses, sent within the process safety time, only containing status information in the detector. It will serve primarily as an "alive" signal, indicating to the safety system that the detector is operating as it should and that the communication link is open. This sequence of packets is shown in FIGURE 4.

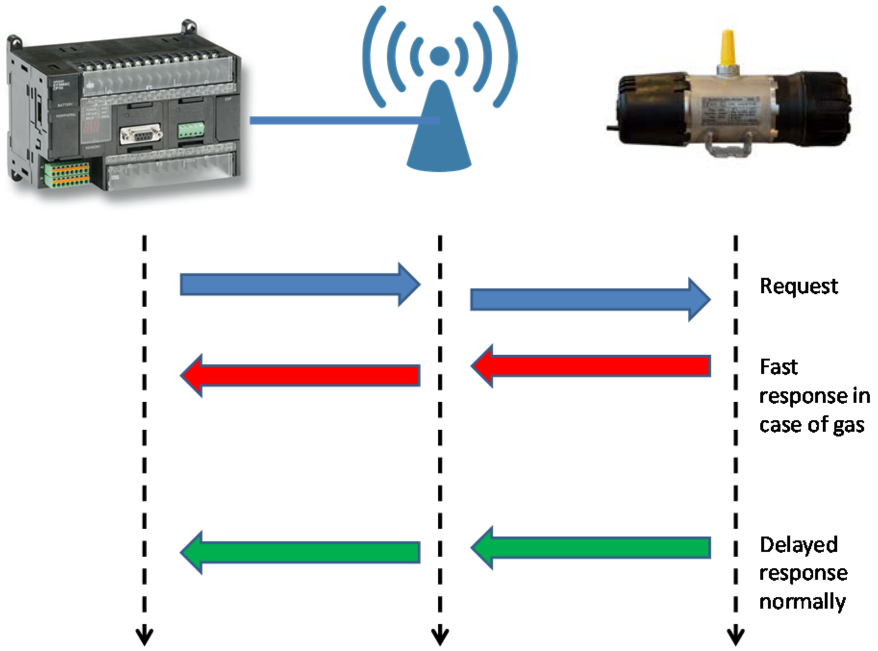


FIGURE 4. A SIMPLIFIED VIEW OF THE GAS DETECTOR COMMUNICATION WITH A SAFETY CONTROLLER THROUGH A GATEWAY ACCESS POINT.

RESULTS FROM FIELD INSTALLATION IN THE NORTH SEA

Three networks of in-total 20 gas detectors were installed at Gullfaks C in January 2013, see FIGURE 5. Gullfaks C is an oil and gas field in the North Sea operated by Statoil. The platform is an old installation having had several add-ons over its more than 25 year lifetime. It has many obstructions from heavy steel decks, structures and machinery that could put the detectors' communication system to the test.

DETECTOR LOCATIONS

Detector locations were partly chosen to challenge and test the gas detector in the most harsh conditions in the North Sea and partly to increase detection coverage at Gullfaks C in a module where only open path detectors were in use. Ten of the detectors at Gullfaks C have been installed shoulder-to-shoulder with Statoil's legacy wired gas detector to compare response times. Locations where there were problems with condensation and beam block on existing wired detectors were chosen. In addition, locations were chosen where strong and turbulent winds were expected, rapid temperature fluctuations and high humidity.

All three gateways communicate back to one fire and gas node executing the safety logic and displaying the result on an ABB safety system in the central control room. The wired side of the installation, from the gateway and beyond, uses PROFInet.

FIGURE 5. STATOIL'S GULLFAKS C PLATFORM WITH INDICATION OF GAS DETECTOR PLACEMENTS.

Main results from the now one year in operation include:

- Stable operation in North Sea environment with availability comparable to wired detectors.
- Actual small gas leakages detected at two instances and with faster response time than the legacy system.
- No drift and stable zero point, no calibration required.
- Response time equal to state-of-the art wired detectors.
- Typical battery lifetime of two years.

RESPONSE TIME

All gas detectors were tested with calibrated 50% LEL methane and flow rate 10l/min. On locations where the wireless gas detectors were installed next to wired detectors, the two detectors were exposed simultaneously through common test gas tubing. The response time from gas flow is open to display at the operator control panel in the central control room were measured, see TABLE I. The tests showed that the response time is essentially equal for both detectors; however the response of the wireless gas detector is quicker to show the correct level of gas. All readings of the wireless gas detector are stand-alone and no filtering is applied as is the case for other infrared detectors.

TABLE I. RESPONSE TIMES OF 10 WIRELESS GAS DETECTORS FROM EXPOSURE TO READING AT OPERATOR CONTROL PANEL.

Tag	Time [s]
DG-M24T-78	6.5
DG-M24T-76	5
DG-M24T-70	5
DG-M24T-72	4.5
DG-M24T-74	6.5
DG-M24T-71	3
DG-M24T-69	3
DG-M24T-73	5
DG-M24T-77	6
DG-M24T-75	7

BATTERY LIFETIME

The battery capacity depends on several factors, most importantly are operational temperature and current draw characteristics. There are two Lithium Thinoyl Chloride (10) battery cells included in the wireless gas detector battery pack. Based on the current draw characteristics, which will vary depending on environment and communication requirements, and taking a conservative approach, the expected battery capacity is 14mAh. Based on the wireless gas detector's measured current draw at Gullfaks C, a battery life of two years is expected, as can be seen from FIGURE 6. Remaining battery life is reported to the control system to allow for maintenance planning.

Three of the twenty gas detectors are placed on especially challenging locations to stress the optical sensor, i.e. with water running over the detector. Power consuming heaters on mirror and window are applied to remove condensation. These are not included in the statistics. On these most challenging locations, the battery lifetime is less than one year.

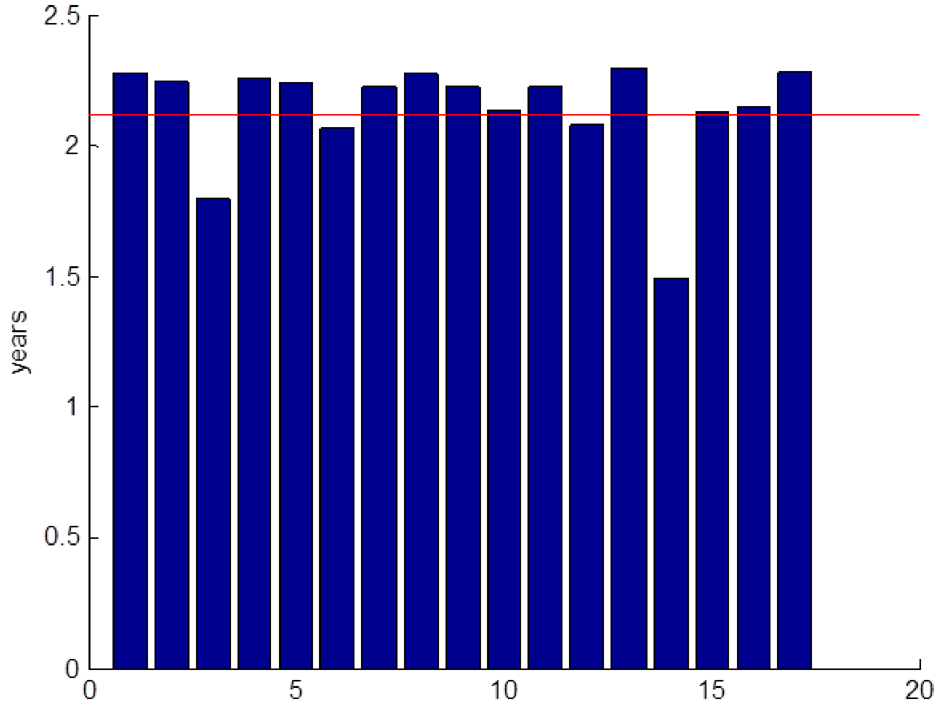


FIGURE 6. ESTIMATED BATTERY LIFE ON WIRELESS GAS DETECTORS INSTALLED AT GULLFAKS C FROM MEASURED ACTUAL CURRENT DRAW. RED LINE SHOWS AVERAGE CONSUMPTION AT 2.1 YEARS.

CONCLUSIONS

A new wireless, battery powered gas detector is demonstrated that is capable of providing reliable detection of hydrocarbon gases in harsh offshore environments, with fast response time and typical two years battery lifetime and no re-calibration.

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