Development of an Autonomous Greenhouse Gas Monitoring System

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***Abstract*—**This paper describes the designs of a first and second generation autonomous gas monitoring system and the successful field trial of the final system (2nd generation). Infrared sensing technology is used to detect and measure the greenhouse gases methane (CH_4) and carbon dioxide (CO_2) at point sources. The ability to monitor real-time events is further enhanced through the implementation of both GSM and Bluetooth technologies to communicate these data in real-time. These systems are robust, reliable and a necessary tool where the monitoring of gas events in real-time are needed.

***Keywords*—**Environmental monitoring, infrared sensing, autonomous system.

I. Introduction

EMERGING trends in environmental monitoring systems lead us to develop autonomous systems that are smaller, cheaper, have longer deployment times and are more robust. The Adaptive Sensors Group have had success in the past building deployable systems for water quality monitoring [1] and this paper describes our foray into the area of real-time air quality monitoring.

In this paper, we have developed a system for the monitoring of landfill gas, the components of which are carbon dioxide (CO_2) and methane (CH_4) gas, both greenhouse gases. The paper summarises development of the first generation system (System I) and then describes in detail the second generation system (System II), which has also been successfully deployed in the field.

Landfill gas is generated by the decomposition of biodegradable waste in an anaerobic environment [2]. The main components are CO_2 gas and CH_4 gas with trace amounts of volatile organic compounds, which are known to cause the malodour of fresh waste.

The main methods of landfill gas reduction on landfill sites is through gas flaring or the use of landfill gas as a fuel on larger landfill sites, exploiting the flammable nature of methane [3]. Since landfill gas collection and the subsequent flaring of this gas were implemented in Ireland, there has been a 33 % reduction in the volume of landfill gas emitted to the atmosphere [3]. Despite this positive result, the monitoring of gas migration to the perimeter borehole wells must still be regularly and reliably monitored. The application of the system design described herein is in communicating the real-time measurements of landfill gas at borehole wells.

The systems described in this paper use commercially available infrared gas sensor technology coupled with wireless communications to monitor CH_4 and CO_2 gases at perimeter borehole wells on landfill sites. The target gas range of the system is 0-5 % volume for both CH_4 gas and CO_2 gas.

The deployable system, secured at the borehole well is capable of taking daily or weekly measurements as instructed. The system communicates the data in real-time once the sampling cycle has been completed. This makes data comparison and modelling of the landfill gas a much easier task.

II. Aspects of Autonomous Environmental Monitoring System Development

Before the development of this monitoring system was fully realised there were a number of considerations to be made. In System I, the most important element was proof of concept, i.e., a sample of gas would be extracted and the sensors could detect the gas at the source. For development of System II, more considerations were taken onboard, i.e., longterm deployment and autonomy. These aspects will be summarised here.

1. Power

The most successful autonomous system will have low power consumption balanced by its capability to scavenge energy from its immediate environment. This will make the system completely autonomous and capable of long periods of deployment, and therefore scalable if the cost base can be kept low. The power consumption of the system is dependent on a number of factors including the number of sensors collecting data, the frequency of sampling, the capacity of battery used and the applicability of renewable power scavenging techniques such as solar panels.

2. Robustness

The system will need to be resistant to the elements through encapsulation in a rugged casing that will ensure the system is resistant to shattering, water and vandals. A way of securing the system at the site is also necessary as theft is an ever increasing problem for environmental monitoring systems.

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3. Data retrieval

Data can be collected in real time, but in order to capitalize on this capability, events must be rapidly defined and detected. Therefore, analytical measurements must be queried at the device level or transmitted to more powerful computation systems for decision making. Wireless communications such as Bluetooth and GSM mean that data can be retrieved in real-time from a site and any problems on-site flagged to various stakeholders and rectified before they become serious.

4. Sampling

Samples must be representative, and the sampling procedure ideally should not disturb the sample. A high sampling rate inevitably drains the power of the system much quicker, while a low sampling rate means that events of interest can be missed, e.g., gas surges or fluctuations. Therefore, the sampling rate is usually a compromise between conflicting demands. The ability to dynamically adjust the sampling rate would consequently be very attractive (e.g., slow sampling rate under 'normal' conditions to conserve power and faster sampling rate when 'an event' is suspected).

III. Sensor Calibration

The sensors used for the detection of CO_2 and CH_4 gases are passive infrared sensors. These are used because they are non-destructive when measuring and have very reproducible results.

Data were collected using the IRCel CO_2 and the IRCel CH_4 infrared sensors, both supplied by Edinburgh Instruments Ltd. The CO_2 and CH_4 sensors were calibrated in triplicate against a calibration gas, sourced from Scott Specialty Gases, containing 5 % target gas in a nitrogen balance. The calibration was in the range 0-5 % CO_2 or CH_4 gas. The standard deviation in the range 0-5 % CO_2 was less than 2 %. This calibration is shown in Fig. 1.

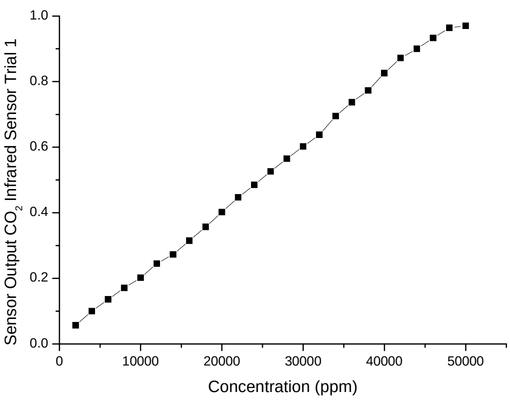

Fig. 1 CO_2 calibration data for IR sensor

The standard deviation in the range 0-5 % CH_4 was less than 2 % and the calibration plot is similar to that shown in Fig. 1.

IV. Development of 1st Generation Prototype - System I

Extraction of a gas sample for analysis using System I is provided by an external air pump. Four parameters of the extracted gas sample, CO_2 concentration, CH_4 concentration, temperature and humidity are measured by the system. The following sections describe in more detail the design features of this system.

(a) Data storage and retrieval

The readings of CO_2 and CH_4 gas concentration, humidity and temperature from the borehole well are collected using an MSP430 (F449) microcontroller and relayed to a laptop computer over an RS232 connection. The data are displayed in a Windows environment using Hyperterminal and logged to file for subsequent analysis.

(b) Power consumption

The power consumption of each infrared sensor is < 200 mA at 5 V [4]. A lead acid battery with a capacity of 7 Ah at 12 V is used in this system. Taking into account the power consumption of the infrared, temperature and humidity sensors and additional electronics, this power source can facilitate a continuous operation of approximately 28 hours. As one sample cycle takes approximately 10 minutes and only one sample cycle is required per day, one battery gives the system an equivalent deployment time of over five months duration.

(c) Housing

The monitoring system is housed in a robust transparent polycarbonate casing (manufactured by Fibox and supplied by Radionics product code 509-3322). This housing is both water tight and shatter resistant, as displayed in Fig. 2. Inlet and outlet fittings (8 mm) are located on opposing faces of the casing for easy access. The system power switch and the back-up RS232 connection port for data acquisition are mounted externally for easy access by the operator.

Fig. 2 System I on field trial

(d) Components

In Fig. 3, the main components of System I can be seen. The battery, the gas sampling unit embedded with the four sensors and the electronics compartment, along with the sampling pump (external to the system) make up the entire unit.

Legend for Fig.3
1. Outlet
2. Electronics Compartment
3. Sampling Cell
4. Battery
5. Inlet

Fig. 3 Internal layout of System I

(e) Sampling Chamber

Fig. 4 displays the sampling chamber, with four sensors embedded into the chamber. There are two infrared sensors – one for CO_2 and one for CH_4, one humidity sensor (supplied by Radionics code 528-43171) and a thermistor (DKF103N5 10 kΩ thermistor) for temperature measurements. The gas is extracted from the borehole well using an air pump operating at a flow rate of 0.6 L/min. The gas pump (AirLite Sampler Model 110-100 distributed by SKC) is housed outside the main unit and the gas is vented to ambient air from the pump.

The sampling unit, with an internal volume of 45 cm^3 was fabricated in ABS plastic using a 3-D rapid prototyping process (Dimension SST 768). Pneumatic hose fittings (8 mm) at either end of the sampling chamber allow connection to the borehole well outlet and the gas sampling pump. Openings of appropriate size accepted four rigidly mounted sensors. Exposed pins allow connection of the sensors to the microcontroller board. The exterior of the chamber was sealed using silicone spray (supplied by Radionics, product code 101-6343). The integrity of this sealing method was verified by closing the chamber outlet and applying a positive internal pressure of 1 bar nitrogen. A valve on the supply line was then closed and an inline pressure gauge between this valve and the sample chamber monitored. No decrease in the 1 bar pressure reading was observed. Therefore, no leaks which would allow dilution the gas sample extracted from the borehole were present in the enclosure.

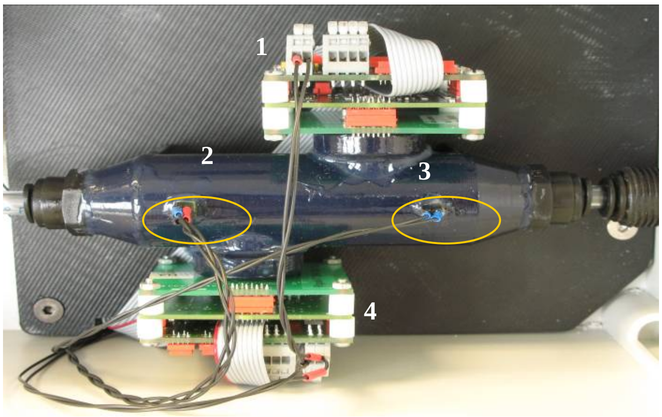

Fig. 4 Detail of sampling chamber

Legend for Fig.4
1. CH_4 sensor
2. RH sensor
3. Thermocouple
4. CO_2 sensor

V. Development of 2^ND Generation System - System II

The next development saw a fully integrated system with 2 batteries, Bluetooth and GSM communications capabilities, and an integrated pumping system to remove the gas sample, all housed in a more robust, easier to manage Peli briefcase.

(a) Data storage and retrieval

Collected data are saved using a 2 Mbit onboard Flash Memory Chip (NUMONYX M25P20). The new communication features in this development phase consist of Bluetooth (LM Technologies Bluetooth Serial Adapter) and GSM (Siemens MC35i).

(b) Housing

The housing is a Peli briefcase, model 1450 in orange, supplied by Kelly Fire & Rescue. This case has a lifetime guarantee and is water tight and shatterproof. It has an external easy grip handle for more practical movement between sampling sites, as displayed in Fig. 5.

Fig. 5 System II on field trial

(c) Components

As depicted in Fig. 6 the layout is somewhat similar to that already described in System I. Here, the pump is integrated into the main system, and there is a GSM modem present to communicate the data at the end of each sampling phase.

Fig. 6 Internal layout of System II

Legend for Fig. 6
1. Battery #1
2. Battery #2
3. Extraction Pump
4. GSM
5. Bluetooth
6. Sampling cell
7. Inlet
8. Outlet

(d) Sampling Procedure

The procedure is automated and consists of a 3 minute baseline, sample and purge routine. The data are subsequently saved to the flash memory chip. The memory is arranged to allow 3x213 data sample slots, facilitating logging of data on device and retrieval in the event of transmission difficulties. A statistical representation of the collected data are compiled and sent via GSM as a text message to a chosen recipient.

VI. Field Trials

Both systems I and II were recently trialled and compared with the established method using a GA2000 system (manufactured by Geotechnical Instruments Ltd. and supplied by Commissioning Services Ltd.)

The systems were connected together through 8 mm PVC tubing. The pump of the GA2000 was used to extract the sample from the borehole well through System I (S1), through System II (S2) and then through the GA2000 system. The gas was sampled for 3 minutes, then disconnected from the tap (which was closed) and finally the systems purged with ambient air for 3 minutes. In all, 14 samples were taken, but only the first 7 samples measuring CO_2 are discussed here.

The correlation between the three systems is excellent, as shown in Table I and Fig. 7. Even though the infrared sensors in S1 and S2 are calibrated between 0-5 %, they still have excellent correlation at 10 % and above target gas when compared with the GA2000 measurements. Figure 8 shows that after each sampling event, the sensors quickly returned to the initial baseline measurement, meaning that repeated measurements are possible and that each individual measurement is representative of the gas being sampled at that time.

TABLE I
DATA COMPARISON FROM FIELD TRIAL FOR CO_2 INFRARED SENSOR

Sample	**GA2000 (%)**	**S1 (%)**	**S2 (%)**
1	6.4	7.2	7.4
2	7.1	8.1	8.2
3	9.6	10.0	10.0
4	10.8	10.8	10.6
5	10.9	11.3	11.2
6	10.8	11.3	11.2
7	10.5	10.8	10.6

VII. Conclusion

The data described from this trial give much confidence that these systems are capable of extracting gas samples from borehole wells and then reliably and reproducibly giving accurate measurements on the gas concentrations present. Further, these data can be transmitted via Bluetooth or GSM communications for analysis at a remote location, making way for this system to become an autonomous monitoring device.

References

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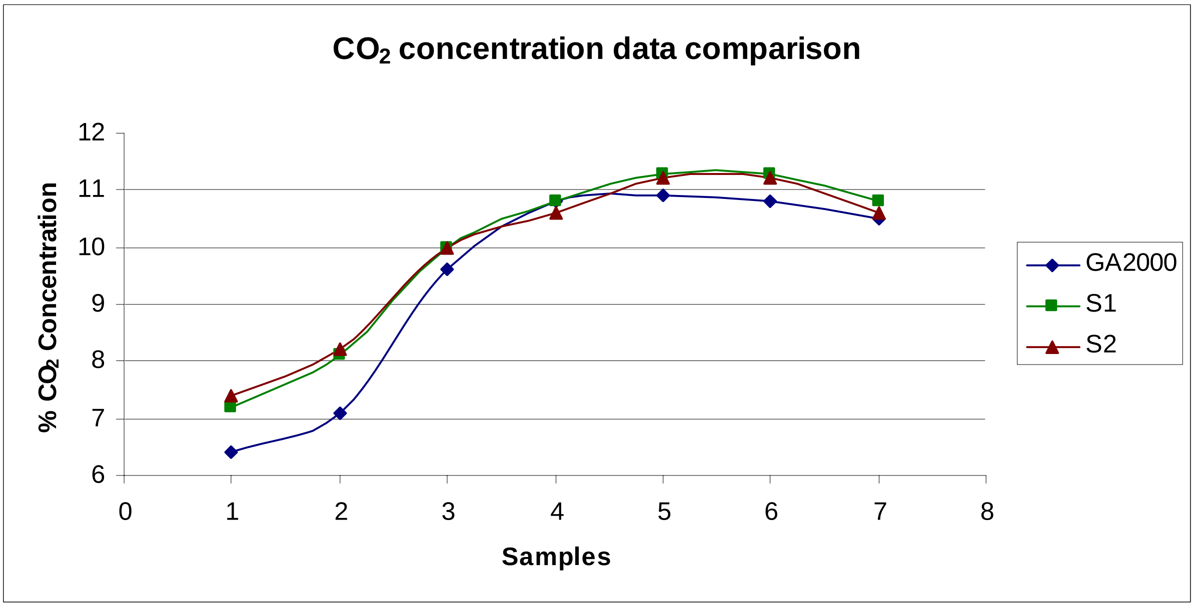

Fig. 7 CO_2 data showing the comparison of System I (S1) and System II (S2) with GA2000

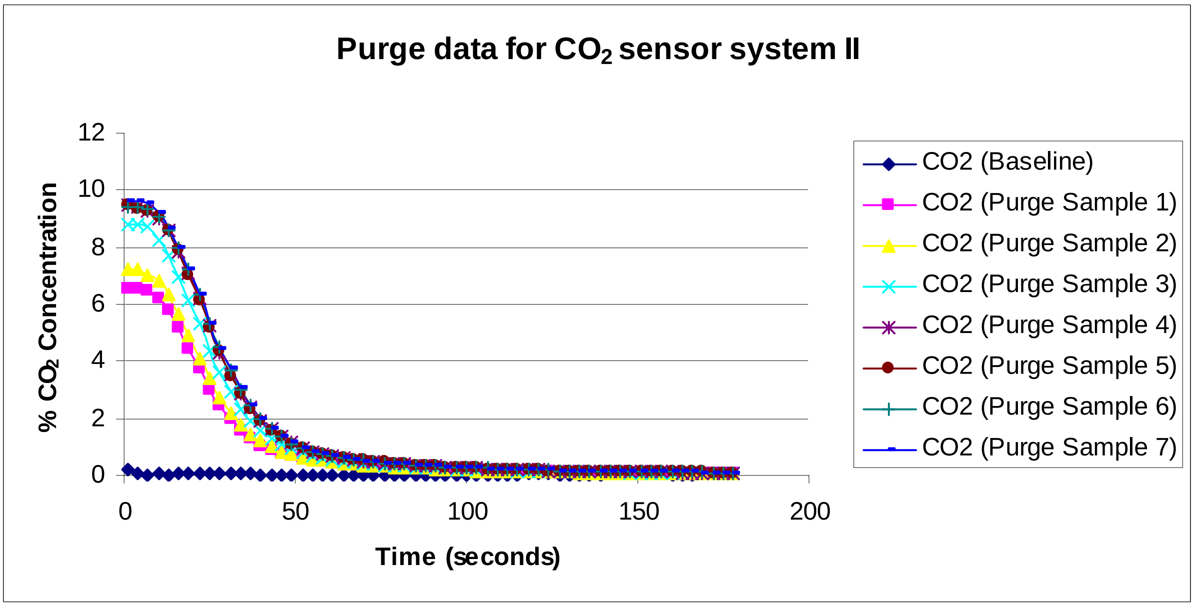

Fig. 8 CO_2 sensor purge data on System II