AUTONOMOUS REMOTE GAS SENSING: WEB-BASED MONITORING OF GREENHOUSE GASES

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EXTENDED ABSTRACT

The control and quantification of greenhouse gas (GHG) emissions is becoming increasingly important in today’s society; from a regulatory perspective, the need to reduce GHGs in order to comply with international directives such as the Kyoto Protocol; from an industrial perspective, the handling and potential utilisation of GHGs arising from their activities; from a social perspective, the mitigation of the harmful effects attributed to GHGs along with maintaining a healthy local environment. Intrinsic to the fulfilment of each of these is the capacity to adequately monitor GHGs. However, long-term sensing at source presents a number of logistical challenges: sensor performance, time duration reliability and, perhaps most significantly, cost viability.

This paper describes the development of autonomous gas sensing platforms with web-based accessibility. The focus has been on achieving long-term reliable performance at a price-point that enables the deployment of multiple distributed systems. Such a wireless sensor network exhibits extensive temporal and spatial resolution, thus defining GHG emissions over the course of time and area for the deployment location in question. This work has been principally targeted at monitoring landfill gas in collaboration with the Irish Environmental Protection Agency. The decomposition of biodegradable waste generates methane (CH₄) and carbon dioxide (CO₂) – these gases must be thermally oxidised by flaring or preferably running an engine if sufficient methane quality. The benefits of autonomous remote gas sensing are twofold: firstly, it will serve to protect local environment by detecting and preventing gas migration beyond the landfill facility perimeter; secondly, it can be used to determine the gas generation potential at various points within the landfill, thus ensuring that the engine or flare receive an adequate supply to maintain optimum operation. Furthermore, these platforms have been employed in different application areas, including quantifying GHG emissions from peat-lands and measuring surface emission from lagoons in wastewater treatment plants.

The web-based accessibility of deployed systems signifies the near real-time accessibility to data. The remote monitoring achieved by these bespoke platforms provides insight into the characteristics of gas emission sources which, in turn, can contribute significantly towards the optimised management of GHG emissions.

Keywords: Environmental monitoring, gas sensing, landfill gas

1. INTRODUCTION

Initiatives to reduce greenhouse gas (GHG) emissions have been driven by long-running international legislation [1], with these efforts set to continue with a targeted 80% reduction in EU-wide GHG emissions by 2050 [2]. To this end, governmental agencies have stated that environmental metrics are to be considered at the heart of policy making.
Key to this is the implementation of monitoring technology capable of accurate and reliable quantitative measurements.

The waste sector is a significant source of GHG generation and has been estimated to account for 5% of the global GHG budget [4]. Landfill gas, comprised primarily of highly potent GHGs methane and carbon dioxide, has been calculated to account for 3.8% of the United States global warming potential [5]. In addition to their global significance as GHGs, these gases also have more localised implications; methane is extremely flammable when existing in the 5–15% v/v concentration in air and carbon dioxide, being heavier than air, is an asphyxiation hazard in nearby subterranean dwellings [6]. Therefore, gas management is one of the crucial aspects of landfill operation. All gases must be extracted and combusted, either by flaring to consume the methane content or by running an engine to produce electricity if methane is of sufficient quality [7]. Landfill facilities must comply with rigorous legislation in order to effectively mitigate against emissions. To ensure against gas migrating into the surrounding soil beyond the confines of the site, perimeter wells are subject to threshold limits of 1.0% and 1.5% v/v for CH₄ and CO₂, respectively [8].

Current practices predominantly involve either sample bagging (capturing a sample for post-analysis with sophisticated laboratory equipment) or manual measurements with handheld analysers. These are time-consuming, laborious and expensive procedures; consequently, measurements have been taken at extended intervals (typically once per month) and with limited spatial coverage. While the need for a more continuous monitoring procedure has been recognised [9], the enabling technologies are yet to proliferate due to challenges in delivering reliable and accurate performance for a viable price-point.

2. SENSOR PLATFORM DEVELOPMENT
An autonomous gas sensing platform has been developed in collaboration with the Irish Environmental Protection Agency. Displayed in Figure 1, this platform is remotely deployable, capable of long-term operation with web-based accessibility to data. The monitoring operation was controlled by a custom-programmed microcontroller board (MSP430, Texas Instruments), managing the gas extraction, sensing (infrared Premier Series, Dynament) and data communication (MC35iT GSM module, Siemens). All sample gas was circulated and returned such that no emissions were vented to atmosphere. A 12V 5Ah lead-acid battery provided a 10 week deployment, with solar charging implemented to sustain battery life indefinitely. The entire assembly was housed within a robust IP68-rated enclosure (Neptune N300, DexGreen) suitable for long-term outdoor deployment.

![Figure 1](image-url). Current platform technology (i) Gas and pressure monitoring platforms as deployed, (ii) Internal view of platform (a) microcontroller circuitry, (b) GSM modem, (c) battery, (d) extraction pump, (e) sensors, (f) sampling ports, (g) IP68 enclosure
Sampling was typically conducted at a frequency of four samples per day, representing a 120-fold increase in temporal resolution compared to the traditional monthly regulatory methods. Acquired data were transmitted via GSM to a base-station in the DCU lab, whereupon the data were parsed and uploaded online for access from a secure web browser. The web-based monitoring via an online portal enabled the site operators and EPA to characterise, for the first time, the dynamics of landfill gas activity in a real-time and fully autonomous process. For example, numerous events which otherwise would have been missed using the existing monthly sampling routine included observations of non-compliant (>1/1.5 % vol. for CH₄/CO₂) and hazardous (5-15 % v/v CH₄ in flammable range) concentrations in perimeter borehole wells [10]. The value-added interpretation of data led to identification of factors contributing to gas level activity, finding strong correlations with on-site extraction conditions and weather (rainfall and barometric pressure) [11]. Furthermore, multiple platforms have been deployed in a wireless sensor network configuration on an active landfill and shown to be beneficial in optimising landfill operational practices [12].

3. GREENHOUSE GAS MONITORING TRIALS

While the platform technology has been developed principally for the landfill gas application, the scope of their applicability has been demonstrated in a number of alternative areas as summarised in the following sections. To illustrate the value-added benefit of such remote data acquisition, the data has been analysed with respect to on-site conditions and local weather patterns. In some cases, the analysis is quantified by means of Pearson product-moment correlation coefficients ("r"), where values approaching ±1.0 indicate a stronger positive or negative correlation.

3.1 Disused landfill extraction network

This deployment was commissioned by the OEE (Office of Environment Enforcement, regulatory branch of the Irish EPA) in order to study gas behaviour on a particular Irish landfill facility. Given that this site was adjacent to an estuary, one specific question to be answered was whether a causal relationship existed between tidal effects and gas concentration levels. This landfill was disused (i.e. no longer actively receiving waste), though gas maintenance has been on-going with a single flare in operation. The gas monitoring system was fitted to a well in-line with the extraction network, see Figure 2(a).

![Figure 2(a)](image)

**Figure 2(a).** Gas levels in borehole G6 in Dundalk landfill facility for 10-month deployment

Gas levels remained relatively low (<3% v/v) for the majority of the deployment period with two notable exceptions occurring in April and June, see Figure 2(b). On these occasions, CH₄ levels were observed to increase abruptly to approximately 10% v/v, midway within the explosive range. Unfortunately, a blackspot in acquired data coincided with this period of time due to battery depletion; an auxiliary
battery pack was developed and installed thereafter (solar panel was not a viable option given vandalism concerns on-site). Discussions with site personnel and analysis of their SCADA data determined that the increases in gas levels were associated to flare downtime due to maintenance. Outside of these isolated occurrences, the data was analysed with respect to local tidal height and weather conditions. Frequency response characteristics were calculated by means of fast Fourier transforms (FFT).

![Figure 3. Frequency analysis by fast Fourier transforms (a) tidal height and (b) borehole gas levels](image)

A peak at 1.93 in the tidal data, as shown in Figure 3(a), indicated just fewer than two tides per day as expected. Implementation of the FFT algorithm for the landfill gas readings showed no dominant frequencies in the CO$_2$ data and a minor cluster of frequencies in the region of 0.25 (representing the peaks in CH$_4$ recurring every 3-5 days as seen in the early stages of data in Figure 2); however, no periodic frequencies linked with tidal height. The lack of association between the gas levels and tidal conditions was further enforced by a negligibly low correlation being calculated ($r = 0.04$). Analysis with respect to data from local weather station revealed slight correlations between gas behaviour and atmospheric pressure ($r = -0.26$) and rainfall ($r = 0.23$).

In summary, there was no reasonable association between tidal conditions and gas behaviour on this particular site, though atmospheric pressure and rainfall magnitudes were identified as being minor contributory factors to gas fluctuations in the well. Abrupt changes to the flare operation could manifest in wells further down along the extraction system as evidenced from substantial peaks in monitored data. The landfill management were surprised at the extent of gas concentrations accumulating in the well when the flare was not under normal operation, an insight into the site’s gas behaviour that has previously been unavailable.

### 3.2 Peatlands GHG generation

Given that many Irish landfills are constructed on boglands, this study was to quantify the inherent generation of CH$_4$ and CO$_2$ gases due to natural vegetation decomposition rather than landfilling activities. Two solar-charged gas monitoring systems were deployed at separate locations within preserved peatlands (i.e. unaffected by peat harvesting or landfilling) as shown in Figure 4(a). The monitoring systems sampled from enclosed headspace of borehole wells, with sample being recycled as per previous deployments on landfill borehole wells [10, 11].
Carbon dioxide was found to be the more prevalent gas present in these particular wells with maxima of 1.7 % v/v and 2.9 % v/v recorded in wells #1 and #2, respectively. These gas levels were notable given that they exceeded the 1.5% threshold limit for CO$_2$ in landfill perimeter wells. CH$_4$ generation was less pronounced, with none present in well #1 (near bog edge) and gradually increasing levels in well #2 (in bog interior).

Gas behaviour was more fluctuant in well #1 as seen in Figure 5(a), most likely attributed to this location near the bog edge and hence less stabilised in terms of moisture content (visual evidence observed on-site, where the ground surrounding well #1 was intermittently flooded and dry). The accumulation of gas levels observed in well #2, shown in Figure 5(b), was more pronounced due to sample recirculation back into well, hence implying an integrated measurement. This was confirmed by measurements when retrieving system #2, where the gas levels dissipated when evacuated.

Analysis of the peatlands gas data with respect to local weather data revealed no strong association to atmospheric pressure or rainfall ($r < 0.1$ for all). The largest correlation values found ($-0.38 \leq r \leq -0.51$) were those pertaining to ambient air temperature. Caution is advised against drawing any definitive conclusions here; firstly the correlation coefficients were relatively low at -0.51 and under; secondly, a negative correlation would be anticipated due to gas levels incrementing (integrated readings due to sample recirculation into the well headspace) and temperatures falling as winter season advances. This latter point was particularly true for data from well #2 as seen in
Figure 6(b): the inverse similarity in the air temperature trend and the CO\textsubscript{2} in this well were most likely coincidental with no conclusive evidence of a causal relationship. There may have been more merit to the correlation calculated from well #1, with discrete changes in CO\textsubscript{2} levels coinciding with peaks and troughs in the temperature data as seen in Figure 6(a). That said, this does not necessarily point to a direct correlation; it merely suggests an association between gas generation and temperature or affiliated conditions (humidity, evaporation rate, etc). This suggestion aligns with the authors’ observation of varying ground moisture content surrounding well #1.

Figure 6. Comparison of peatlands CO\textsubscript{2} activity and air temperature for (a) system #1, (b) system #2

In summary, low but appreciable quantities of gas were found to emit naturally from peatlands, particularly CO\textsubscript{2} in this case. Levels of CO\textsubscript{2} were shown to exceed the threshold limit defined for landfill perimeter wells, thus indicating that these levels could be surpassed in a landfill site depending on the inherent properties of the substrate material. The time-dependent gas behaviour was found to differ between the sampling locations (near bog edge compared to bog interior) – this could be attributed to the bog interior being more stabilised in terms of ground moisture content.

3.3 Wastewater treatment lagoon emissions
This deployment resulted from an inter-university collaboration between USP and DCU, resulting in a gas monitoring system was assembled and shipped to Brazil. The USP team engaged with SABESP, the Brazilian state-owned water utility organisation, who were interested in quantifying gas emissions from an anaerobic lagoon in a wastewater treatment plants (WWTP). As the lagoon is exposed to atmosphere, an accumulator bag has been placed on the water surface to capture the gas emissions.

Figure 7. GEN2 gas monitoring system deployed on wastewater treatment plant in São Paulo
Within days of the deployment commencing, significant gas levels have been observed to accumulate, particularly CH₄ levels to exceed its flammability range. Other distinct events were clearly identifiable in Figure 7; a sudden reduction in gas levels on October 17ᵗʰ ('A') when the accumulator bag was shifted and partially spilled, and daily periodic fluctuations in gas concentrations from October 24ᵗʰ ('B') onwards.

The quantification of this gas behaviour has been generating substantial interest from SABESP, who are interested in expanding the number of deployments. They are particularly interested in use of the data to evaluate the processes within the WWTP, to reduce gas emissions by varying additive agents, water agitation and flow conditions.

4. CONCLUSIONS

Autonomous monitoring platforms with web-based accessibility have been developed for the application of monitoring greenhouse gases. These platforms have been applied principally on landfill sites, with applicability demonstrated for alternative gas emission sources such as peatlands and wastewater treatment plants. The successful operation of these platforms in collecting and visualising an abundant wealth of insightful data on gas characteristics, as exemplified by the collaboration with the EPA, demonstrate the potential usefulness of such platforms. With 2013 being labelled the 'Year of Air’ by European leaders, it has never been more important to attain extensive, accurate and relevant environmental metrics. This project has progressed towards this goal by developing a monitored service using low cost but reliable remote sensor platforms. This delivers the increased frequency of monitoring required by the regulators, the enhanced operational and performance monitoring that is beneficial to the operators and the low cost operation that enables increased scale of deployments.

Continued development is ongoing with these platforms with a focus on commercialisation. Such work is motivated by the reduction of component cost, implementation of different sensor and telemetry options to meet the demand of the application, and the conducting of further extensive field trials in order to bring this technology to market.

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