Drone-based gas leak detection system for use in industry

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ABSTRACT

Gas leaks pose a prevalent issue in industry and can have pressing impacts on individual safety and the environment. There is demand for new technologies that can ease, and reduce the cost of, detection of the source of leaks, both on a large and small scale. We present a device capable of visualising the gas involved in the leaks allowing for an accessible tool in source location. Our current device can image methane leaks from ranges of up to 10m. By imaging a scene illuminated using a laser diode tuned to an absorption band of methane, followed by imaging at a similar but non-absorbed wavelength one can build a differential image of the scene and identify the presence of methane. This differential signal is then processed and assigned a false colour, in order to be overlaid upon an accompanying visible live feed. This system is adaptable and could be used to detect other gas species with modification to light source and detector. Future candidate gases would be based upon industry interest with acetylene, a common and flammable welding gas, being an example. The system is also robust enough to be drone mounted, we present data from conducted test flights. These flights demonstrate new ways in which the system can be used, such as in monitoring of difficult to access pipe geometries and for preset flight paths along expansive pipelines. This can allow for a more automated gas detection process, that is straightforward to review.

Keywords: Methane, UAV, Gas Detection, Gas Imaging, Real-time Imaging, Industry

1. INTRODUCTION

The detection mechanism used in this research builds upon the GasSight, first published in "Developing a portable gas imaging camera using highly tunable active-illumination and computer vision" by Nutt et al.[1] This is a methane gas imaging camera which allows one to directly image methane gas in real-time. The device is easy to use and the feedback provided allows a user to directly interpret the location of the gas in a given scene. The immediacy of gas location means that the GasSight is ideal for gas leak detection and mitigation and the source of leaks can be found by simply moving the camera.

The mechanism for GasSight means that it could be well suited for unmanned aerial vehicle (UAV) mounting, such as on a drone. The aim is that an easy to use gas detection tool could be widely adopted by industry to locate and prevent gas leaks into the environment. Preventing gas leaks has a high benefit to both safety and to the environment as methane is a greenhouse gas as well as flammable. Performance whilst drone mounted needed to be monitored in order to ascertain whether the system itself would be sensitive and robust enough to detect gas from the underside of a drone. Care had to be taken to accommodate for the systems sensitivity to sunlight pollution in its' current state. A series of flights were undertaken at various points during the day and compared. These results were impacted by external factors, such as sunlight brightness and post-processing strength.

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2. BACKGROUND

Industrial methane gas leaks have a profound impact upon the environment, as well as having knock-on effects upon the finances of the company responsible.[2,3] Methane is widely used as a key component of natural gas fuel systems, largely adopted due to it's decreased carbon dioxide release.[4] The environmental impact of methane is of key interest in current times due to it's role as a key greenhouse gas. Methane's action as a greenhouse gas is relatively short lived, but very potent. For comparison methane will exist in the atmosphere for 12 years compared to carbon dioxide which remains for upwards of a century, however methane is 25 times more effective per mole as a greenhouse gas than carbon dioxide.[5,6] It is thought that by monitoring current methane usage and leakage the short term impact on climate change can be drastically lessened whilst more permanent, clean solutions can be found.[3,4] Methane gas leaks can also be dangerous to individuals. Methane is an asphyxiant as well as having a lower explosive limit of about $4.6 \pm 0.3\%$ and an upper explosive limit of $15.8 \pm 0.4\%$.[7]Undetected leaks of methane gas can lead to large scale explosions which can cause fatalities.[7]

Whilst there are natural sources of methane leakage such as from seepage and geothermal, the focus of this research will be that of man-made sources.[8] The volume of methane released into the atmosphere from anthropogenic sources is great, with it estimated that as much as 2.3% of natural gas in pipelines in the U.S.A. is leaking into the atmosphere.[9] Similarly, in the UK, approximately a third of the methane emissions are from landfill sites.[10] Sustained pipeline leaks can cause a reduction of air quality in urban environments and in the most extreme cases can lead to explosions.[11,12] Sometimes the impact of the leaks can be exacerbated by the high pressure nature of the pipelines meaning that leaks can be more hazardous from these systems.[13] Also of note is the fact that many of the pipelines used are of ages greater than 50 years - meaning they are far more prone to deterioration and thus leaks.[5]

One key way to reduce the impact of methane leakages into the environment is to identify, locate and prevent them more efficiently.[12] This goal could be achieved by automating the servicing of pipeline checks and making them far more routine.[12] A proposed method for automating these check-ups would be to affix sensitive detection systems to a drone and utilise pre-programmed routes to fly along pipelines or across facilities.[14] The quicker the system is to set up and the easier the flight data is to review the more likely these techniques are to be widely adopted across industry.[15]

The type of data that the device records is of high importance, with data that requires little post processing being desirable due in part to a reduced need for specialised training. Ensuring that a system maintains a high level of ease of is of high priority in the work conducted.

Another issue that must be taken into consideration with UAV based detection methods is that of the down-draft. The down-draft is the air currents created below the rotors of the UAV which may act to displace gas that otherwise could have been imaged.[16] Devices for use on helicopters also exist but the down-draft is much greater and the increased size places restrictions on the areas that can be accessed and the range of detection.[17]

3. DEVICE CHARACTERISTICS

GasSight's methane detection mechanism involves illuminating a scene with infrared diodes and collecting the back-scattered light on a short-wave infrared (SWIR) sensor. The two wavelengths used are around 1653nm, one of which is absorbed by methane at 1653.7nm and a nearby wavelength that is not absorbed. By taking an image at each of these wavelengths in succession a differential image can be generated and the presence of any gas inferred. The differential signal undergoes a level of post-processing to remove noise and smooth the overall signal. Similarly, care is taken to account for situations where the camera has moved and the two images no longer perfectly overlap. Techniques such as phase correlation and erosion and dilation are utilised to minimise the impact of artefacts caused by these movements.[18,19] This processed differential image is then assigned a false RGB colour value and added onto a live colour feed that is being simultaneously captured. The use of a cold mirror allows the visible and infrared cameras to be co-linear, meaning a one time alignment offset can be applied in post-processing to ensure the differential SWIR signal overlaps with the correct position in the visible feed. An example frame is displayed in Figure 1.

In mounting the GasSight to a drone certain factors must be considered. Firstly it must be remembered that in order to detect gas, back-scattered light must be detected. To ensure this whilst attached to the UAV the

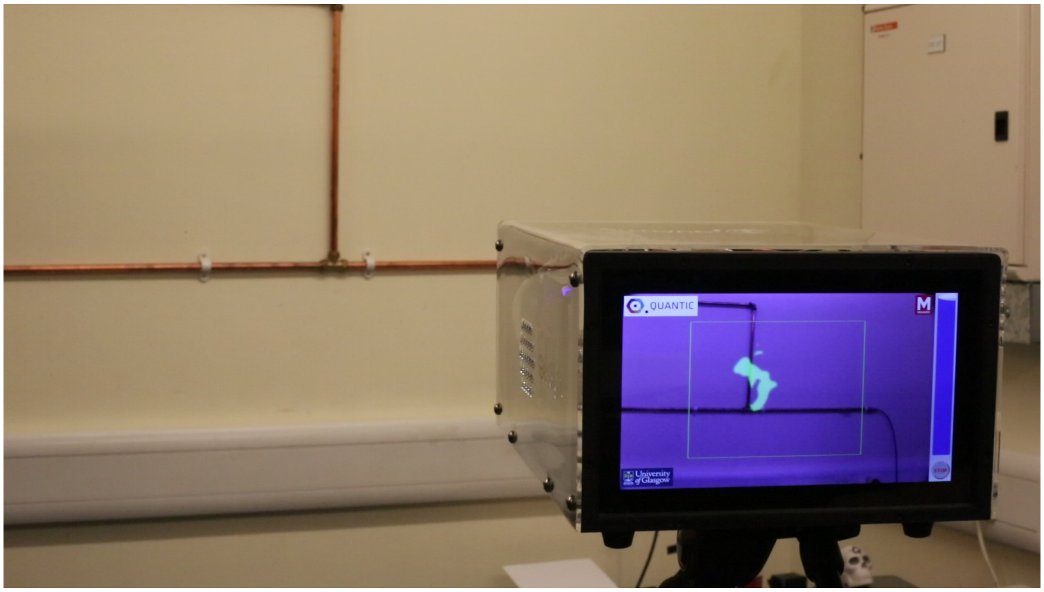

Figure 1. Example frame of a gas leak observed using the GasSight system. The gas flow rate observed here is 0.2L/min which is akin to those found in domestic settings. This highlights the GasSight's ability to detect gas in real world scenarios.

camera must be angled downwards. In angling the GasSight downwards this uses the ground below the system as a surface for back-scattering. Different surfaces have different back-scatter properties but in general success has been found with most surface types including grass and concrete. A ground sheet was brought to ensure a more uniform back-scatter for all drone based exposures regardless of location and surface type, but it was deemed unnecessary ultimately. Secondly, the range of the system must be carefully considered. The in-lab range of the GasSight sensitivity is dependent upon exposure time of the camera and the power of the illumination diodes. Outside of the lab sunlight saturation becomes an issue and as such the exposure time, and thus sensitivity and range, is reduced to accommodate this. Range is also affected by the resolution of the camera and also the strength of the image processing filter such as the erosion and dilation, but in general a safe estimate to the overall range of the system is about 10m outside with a SWIR exposure time of 20ms.

4. DRONE PERFORMANCE

The GasSight was affixed to the the underside of the drone (Matrice 600 Pro) by using a mount attached to the weight bearing supports. Care was taken to ensure that the mass of the GasSight did not exceed that of the maximum take off mass of the drone system. The recommended load mass for the Matrice 600 Pro is 5.5kg and the attached GasSight model was 3.1kg. The GasSight is then angled towards the ground in order to provide back-scatter of the SWIR illumination. A max altitude of 3m was selected to ensure that gas signals on the ground level would remain visible, whilst also ensuring a suitable height to allow down-wash to dissipate sufficiently. In reality a height of 3m seems reasonable for applications - as the imaging is taken at an angle, signal should generally be free of down-wash effects and also reduces risk of damage from a drone failure as the distance to fall is relatively low. It is envisaged that flying at an altitude of 3m above a pipeline would be acceptable for example. A HDMI connection between the camera output and the drone meant that a live stream of the cameras feed could be viewed at all times on the device used to control the drone.

The combined system was then flown in four separate scenarios: a test flight using an empty GasSight casing loaded to be of equivalent mass of the real GasSight, in direct sunlight during the day, in the absence of sunlight after sunset and in low light conditions during sunset. The test flight was performed to practice the flight controls whilst ensuring that the system was secure and that the drone performance would not be hampered by the attached load and distribution. It was concluded that the attachment to the drone was secure and that control of the system was predictable and uncompromised by the load. The further three flights gave far more insight into the performance of the combined system. The aim of these three flights was to image a clear balloon filled with methane gas.

The daytime data was perhaps the most informative. Due to the impact of the direct sunlight there was an overall lack of sensitivity in the measurements, however the use of a backboard with a coating of retro-reflective tape allowed range and stability tests to be conducted. The retro-reflective board provides a cooperative back-scatter to artificially increase the range. However, while it is not representative of a real use application it does demonstrate that movement noise and other such issues are not a significant factor despite initial concerns. The main issue however was that the gas balloons not attached to the backboard could not be detected at all due to sunlight interference, this can be observed in Figure 2. The gas detection properties of this data set was concluded to be limited due to the requirement of a retro-reflective board as well as the the loss of sensitivity due to high sunlight levels.

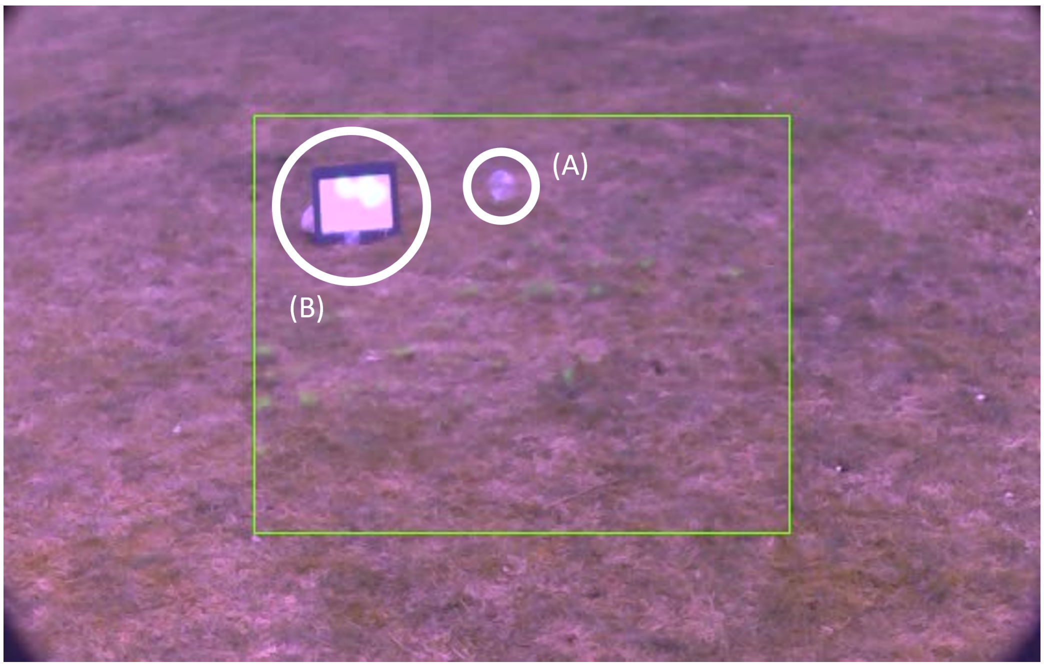

Figure 2. Example frame from a daytime flight, taken at a horizontal distance of approximately 10m and an altitude of approximately 3m. (A) balloon against the grass is not visible, as a result of the high sunlight levels. (B) the gas balloons are clearly visible when mounted against the cooperative back-scatter board.

The second flight taken at nighttime was more successful in terms of data acquisition. The balloons were directly observable against the grass they lay upon, no ground sheet or retro-reflective tape was necessary. One issue that did arise was the fact that the attached visible camera had lost most of it's sensitivity and as such the feed provided via the live stream made locating the balloons tricky, as can be seen in Figure 3. In future iterations of the GasSight design a light source can be attached such that it can illuminate a scene without saturating the SWIR signal. A sufficiently powerful white LED could work as a suitable candidate as there would be no additional SWIR illumination in the same band as the utilised filter. By illuminating the balloons with a torch they could be located and imaged. It was found that with current settings the balloons began to be resolved at a horizontal distance exceeding 10m, but at 10m the differential signal recovered was stable and clear hence many flights were conducted at this range. This flight proved that the system was capable of identifying gas leaks reliably from the drone, against a back-scattering media of grass.

The final set of flights conducted were performed during sunset where light levels were decreasing over time. The initial few flights suffered from a reduced sensitivity, but not to the extent of the data taken during the initial daytime data set. This reduced sensitivity mostly manifest as an increase in overall noise in the feed due to variations in the sunlight levels entering the system. As the night progressed the noise levels decreased and

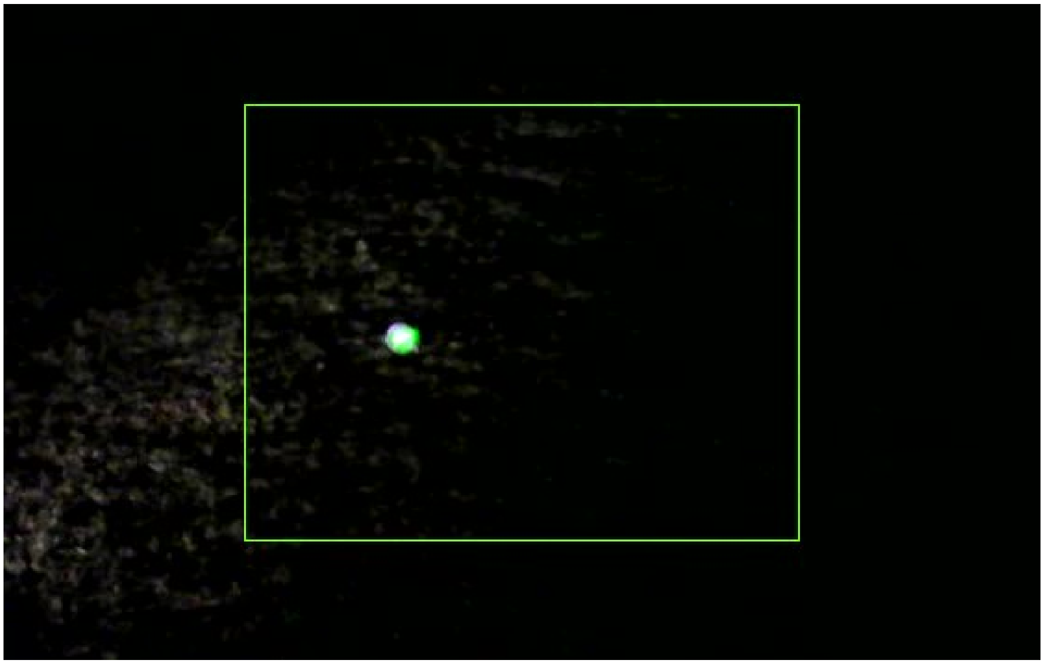

Figure 3. Example frame from nighttime flight, taken at a horizontal distance of approximately 6m and an altitude of approximately 3m. The gas balloon is clearly visible without the use of a co-operative back-scatter but the scene must be illuminated by an external source in order to see where the balloon is on the visible camera.

as such the clarity of the image is increased. The much later flights suffer from the same loss of visibility in the visible camera feed due to a lack of a light source. The flight data recorded between these two times however is very stable, with little noise getting through the filters and a clear visible feed also present. These flights are the best example of the capabilities of the system, with the gas balloon clearly visible when the drone flies within range.

5. CONCLUSION

Overall, the integration of the GasSight system onto a UAV was a success. It has been demonstrated that the system is easy to use and manoeuvre. This ease of use promises to make this form of device straightforward to adopt into industry as it requires no specialist training. The data that the device records is entirely visual and as such, is straightforward to review and simplifies the detection and prevention of methane gas leaks.

The combined system currently suffers from sensitivity impairment in direct sunlight. Future work will involve tackling these limitations, the current proposed solution is to increase the power of the diodes such that the exposure time of the system can be decreased. This combination of increased power and decreased exposure time should lead to comparable signal strength but with less sunlight pollution. The UAV system has also up until this point only been used to image gas enclosed within a balloon, future tests should aim to find a way of safely demonstrating detection capabilities with a simulated leak or gas cloud.

It is hoped that once these issues have been addressed the system can be taken to a variety of onsite locations. By using the system in real world scenarios practical usability can be directly assessed. On site demonstrations will also provide a valuable opportunity to obtain feedback and learn about concerns from prospective users, which can then be taken on board in order to improve the system for more widespread use. Direct interaction with industry should highlight the strengths and weaknesses of the device and the demand for a product with such capabilities far more directly than in academic studies.

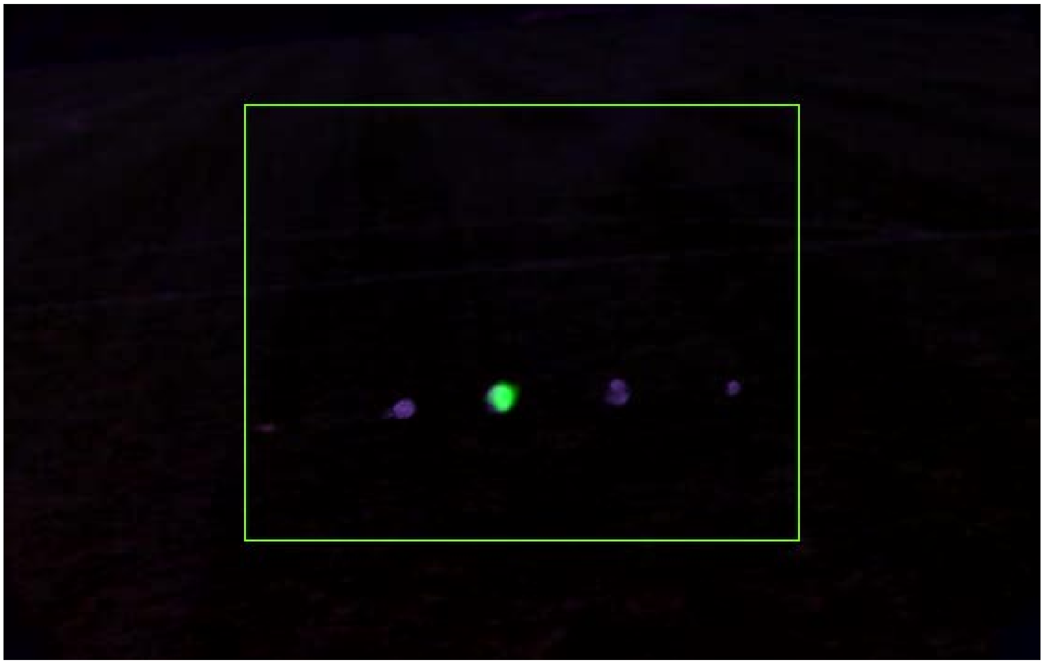

Figure 4. Example frame from an evening flight, with an approximate horizontal distance of 10m and altitude of 3m from the balloons. It can be seen that despite lower visibility on the visible camera, the methane filled balloon can clearly be distinguished from the nitrogen filled balloons.

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