Methane Detection Using Unmanned Aerial Systems

September, 2017

ABSTRACT

Through the use of unmanned aerial systems, researchers from the United States (Princeton University, American Aerospace Technologies) and Germany (Karlsruhe Institute of Technology) have developed a mid-infrared methane-sensing instrument that can be autonomously flown to measure methane levels at different locations and altitudes. This instrumentation must be small and lightweight, due to the payload requirements of the flight systems, without sacrificing precision. Using a Wavelength Electronics LDTC0520 to drive a GaSb laser, wavelength modulation spectroscopy was used to measure the methane levels in-flight. Measurements were taken in New Jersey and Germany, and showed repeatability, robustness, and high precision. Their work shows that these systems can be used to further study and understand how methane levels vary due to altitude, human impact, and geographical location.

WHY?

Methane (CH_4) can be used as an indicator for climate change. Studying methane levels in air can give insight to various factors impacting the atmosphere. Further study may lead to understanding of wetland evolution, as well as impacts of livestock and equipment usage on the atmosphere.

Studying methane levels in the air is not a new or novel concept. However, work done previously has had downsides, some of which will be discussed in the next section.

The researchers chose to implement their methane-detection instrumentation on unmanned aerial systems (UAS). By doing this, they had control over where and how the in-flight measurements were taken.

The ability to pre-program flight patterns gives UAS another advantage – they are semi-autonomous.

Utilizing UAS is a relatively new approach to air and gas sensing, and the work presented here proves that this approach is feasible. Much of the work done previously with UAS had lower precision, or was unable to meet the typical payload requirements.

Here, the researchers present a method which has high-precision, and fits the payloads of a typical fixed-wing UAS, or a hexacopter setup.

PROBLEMS WITH OLD SYSTEMS

There have been successful methane-sensing systems implemented previously. These systems have been both ground-based, as well as airborne.

The ground-based systems have been deployed in static detectors, and mobile laboratory scenarios. Neither of these situations is ideal, as they are "more time-consuming, and may miss elevated leak sources." [1]

Those systems utilized in airborne detection of methane have downsides as well, namely that they have generally been installed on large aircraft or balloons. While this makes system design much easier, due to the loose requirements on size, power consumption, and weight, these systems operate at much higher altitudes than is desirable. In the case of balloon-deployment, there is also little to no control over the measurement location after launch. Ideally the methane-sensing system would operate with flight path control near the surface of the earth, where the majority of the methane emissions are.

A limited number of designs have been presented that are lightweight and compact enough to be flown on unmanned aerial systems. The use of UAS allows for optimal altitude measurements. However, these systems thus far have utilized near-infrared (NIR) excitation. This NIR excitation is far from the fundamental absorption band of methane.

Given the cons of both ground-based sensors, and large aircraft mounted systems, UAS equipped with a mid-infared (MIR) light source are a promising solution for accurately determining methane levels.

HOW?

The researchers installed an MIR-based methane sensor on two different UAS. The first was a fixed-wing UAS, which has long-range flight capabilities (see **Figure 1a**). The second was a hexacopter UAS with enhanced maneuverability (see **Figure 1b**).

Both flight systems utilized the same optical cell and electronics to perform wavelength modulation spectroscopy (WMS) measurements of methane in-flight.

The modulation requirements of the WMS were twofold. First, a 200 Hz sawtooth signal was applied to the injection current to vary the output wavelength as a function of time. Second, a 20 kHz sine wave was superimposed with the sawtooth signal. This additional sinusoidal modulation allows the resulting signal to be decomposed into harmonics of the input. This method eliminates much of the background noise, since the background is not a harmonic of the input sine wave. Thus, the signal-to-noise ratio of the detection instrument is increased.

A gallium-antimonide (GaSb) distributed feedback laser was used, with a central emission of 3057.4 cm^{-1}. The modulation described above introduces 1.2 cm^{-1} of tuning about the center. This tuning covers the fundamental band of methane absorption in the mid infrared.

To achieve repeatable tuning, the central wavelength of the laser cannot change. Like other semiconductor lasers, the emission wavelength of GaSb lasers depends on temperature. At an altitude of 600 m above ground level, the researchers calculated that there should be a temperature drop of approximately 3-6 K. Given the fluctuating ambient temperatures, it was imperative that the temperature controller be able to adapt and keep the laser temperature stable throughout the duration of the flights.

The laser and optical components are arranged in an open-cell multi-pass configuration for making the methane measurements. The open-cell design allowed for lower mass (no tubes and pressure systems). The multi-pass optical path allowed for a smaller footprint of the system, by compressing a 2.7 m optical path length into 24 passes through an 11.2 cm path.

An in-line methane reference cell was used to ensure accuracy of the system. This is different than typical reference cells, being composed of the actual target gas, as opposed to a gas with a non-overlapping spectrum.

Altitude, temperature, pressure, and GPS location were also collected during flights. This allowed additional analysis for environmetal factors impacting methane levels.

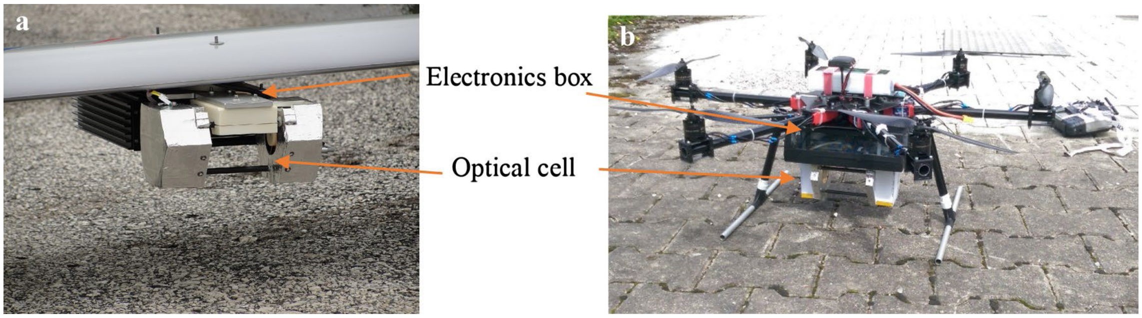

Figure 1. Methane-sensing instrumentation mounted on (a) the fixed-wing UAS and (b) hexacopter UAS.

FIXED-WING MEASUREMENT SYSTEM

With the measurement system mounted onto the fixed-wing apparatus, there were less stringent mass and size specifications to be met. This allowed the researchers to find the best possible configuration of optical components and electronics for their design.

The fixed-wing UAS had a payload of 25 kg and a maximum flight time of 16 hours. All of the sensor electronics were confined in a 20 cm x 26 cm x 11 cm box, which was mounted underneath one of the wings of the aircraft.

In addition to the small size of the apparatus, it had to be rugged as well, with the ability to withstand forces up to 10-g upon launch.

The fixed-wing system made flights around southern New Jersey, based out of the Cape May Airport, as shown in **Figure 2a**.

HEXACOPTER MEASUREMENT SYSTEM

In comparison to the fixed-wing aircraft, the hexacopter has a much smaller payload of 2.1 kg, and a maximum flight time of 5-6 minutes. This required a reduction in the overall mass in order to meet the flight requirements.

These mass-reduction efforts included a change from an aluminum electronics case to a plastic one, a reduction in the size of the optical cell housing, and a combination of the sensor head and control electronics into a single box. All of these reductions took the overall mass of the system from 4.68 kg to 1.59 kg, while also reducing the overall footprint of the system to fit onto the smaller hexacopter UAS.

The hexacopter made flights around Fendt, Germany as part of the ScaleX campaign. In these flights, the data taken by the hexacopter were compared with a 9 m tower, equipped with three air inlets at various heights connected to a Picarro methane analyzer, see **Figure 2b**.

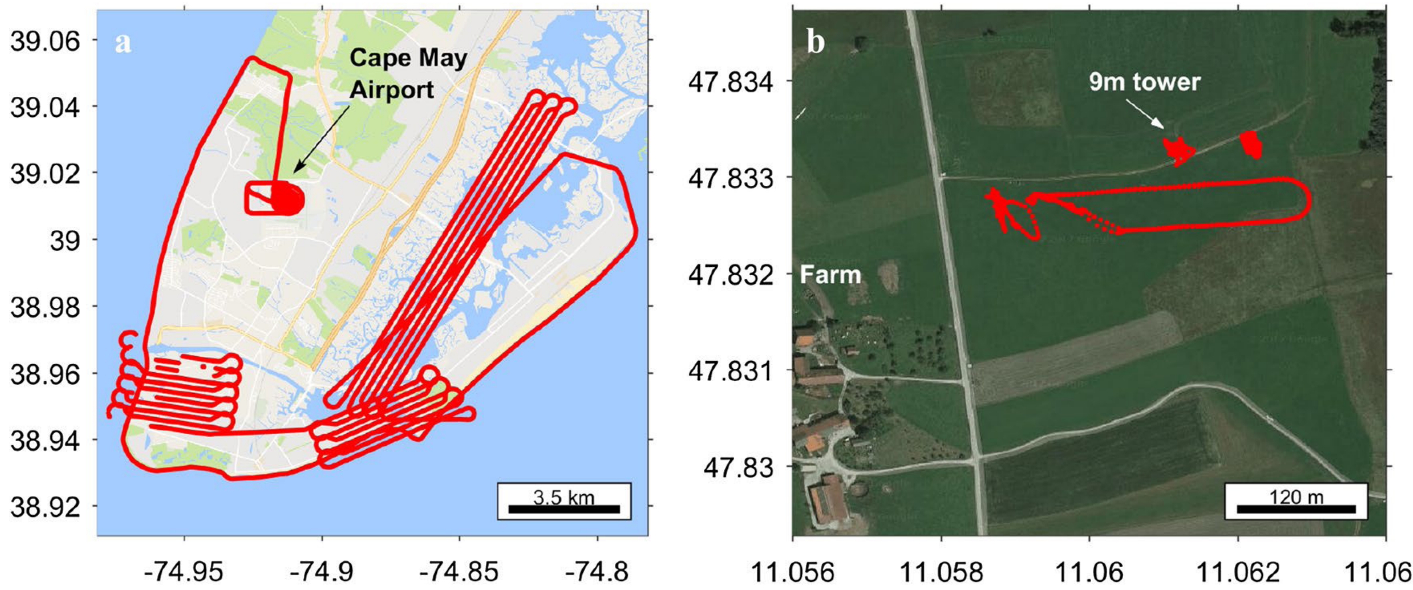

Figure 2. The flight paths are shown in red, overlaying the corresponding satellite images of (a) southern New Jersey, United States and (b) Fendt, Germany. The Picarro-equipped tower around Fendt is labeled in (b). In each image, the x-axis corresponds to longitude, while the y-axis shows latitude.

RESULTS

After the flights of the fixed-wing and hexacopter UAS, the researchers found that the precision of the fixed-wing system was 5 ppbv/√Hz, and the hexacopter system was 10 ppbv/√Hz. Each system "meets previously estimated criteria of <40 ppbv needed to quantify emissions at a landfill." [1]

FIXED-WING RESULTS

With its ability to hold larger and heavier equipment, the fixed-wing system showed the highest precision of the two UAS methane sensors. In fact, this design, when used in a controlled laboratory environment with calibrated standards showed a precision of 4.5 ppbv. This indicates that the in-flight measurements are only 0.5 ppbv away from the maximum precision that the instrument can measure, even with the variable flight conditions.

To further prove the value of the fixed-wing system, 6 vertical profiles were measured over the course of 15 minutes. These profiles, ranging in altitude from 120 to 583 meters above sea level (m a.s.l.), showed repeatable results.

Figure 3 depicts these profiles in two ways. First, a time series is shown, where altitude and methane levels are presented independently. Second, methane as a function of altitude is plotted, for each vertical profile. The vertical profiles are defined in a peak-to-valley or valley-to-peak fashion. For example, the first vertical profile, beginning at 15:45 local time, started at an altitude of 430 m a.s.l. and ended at an altitude of 120 m a.s.l.

The structure shown indicates consistent methane minima around 130 and 400 m, whereas the methane maxima occur around 240 and 500 m. This repeatability is evidence of the sensor's capability to resolve atmospheric methane variability.

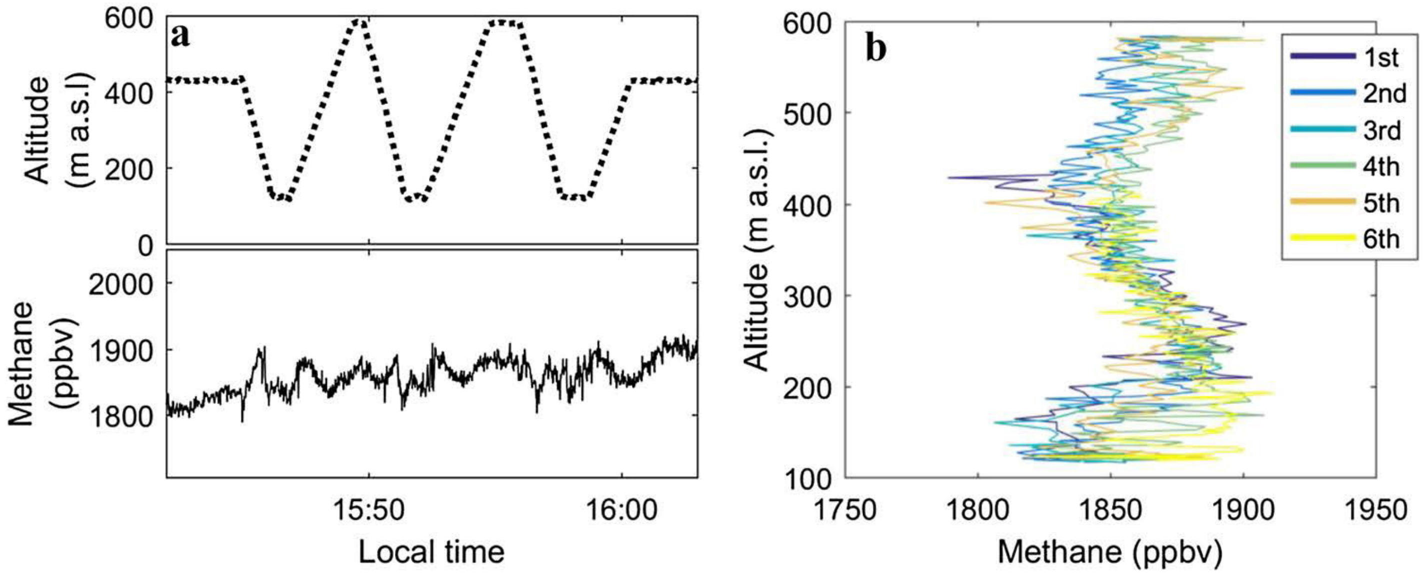

Figure 3. Methane data from the fixed-wing UAS instrument during flights in New Jersey. (a) is a time series of the data, with 6 vertical profiles from 15:45 to 16:00 local time. (b) shows the methane levels as a function of altitude for each profile during the same time period, with repeatable maxima and minima.

HEXACOPTER RESULTS

Due to its short flight time capability, the hexacopter UAS was used to make 6 recorded flights between 21:00 and 06:00 local time during ScaleX.

As a check of accuracy, the data acquired during these flights was compared with the Picarro-equipped methane-sensing instrument. The tower that the Picarro instrument was attached to has air inlets at 1, 3, and 9 m above the ground. Only one air inlet is open at a time, allowing the three inlets to be attached to a single instrument.

Each flight that the hexacopter took recorded methane levels as a function of altitude, up to 150 meters above ground level (m a.g.l.).

In **Figure 4** the data for both the Picarro instrument and the hexacopter UAS are presented. The data for the Picarro instrument (open circles connected by lines) generally shows the same trends as the hexacopter measurements (cross marks). For clarity, the 3 m inlet is not plotted; it showed similar trends to the 1 and 9 m inlets. An additional hexacopter measurement at 49 m a.g.l. is plotted.

Both systems showed remarkable precision, as well as durability over repeated scans. This proves the usability of these unmanned aerial systems for further study of methane levels in the air.

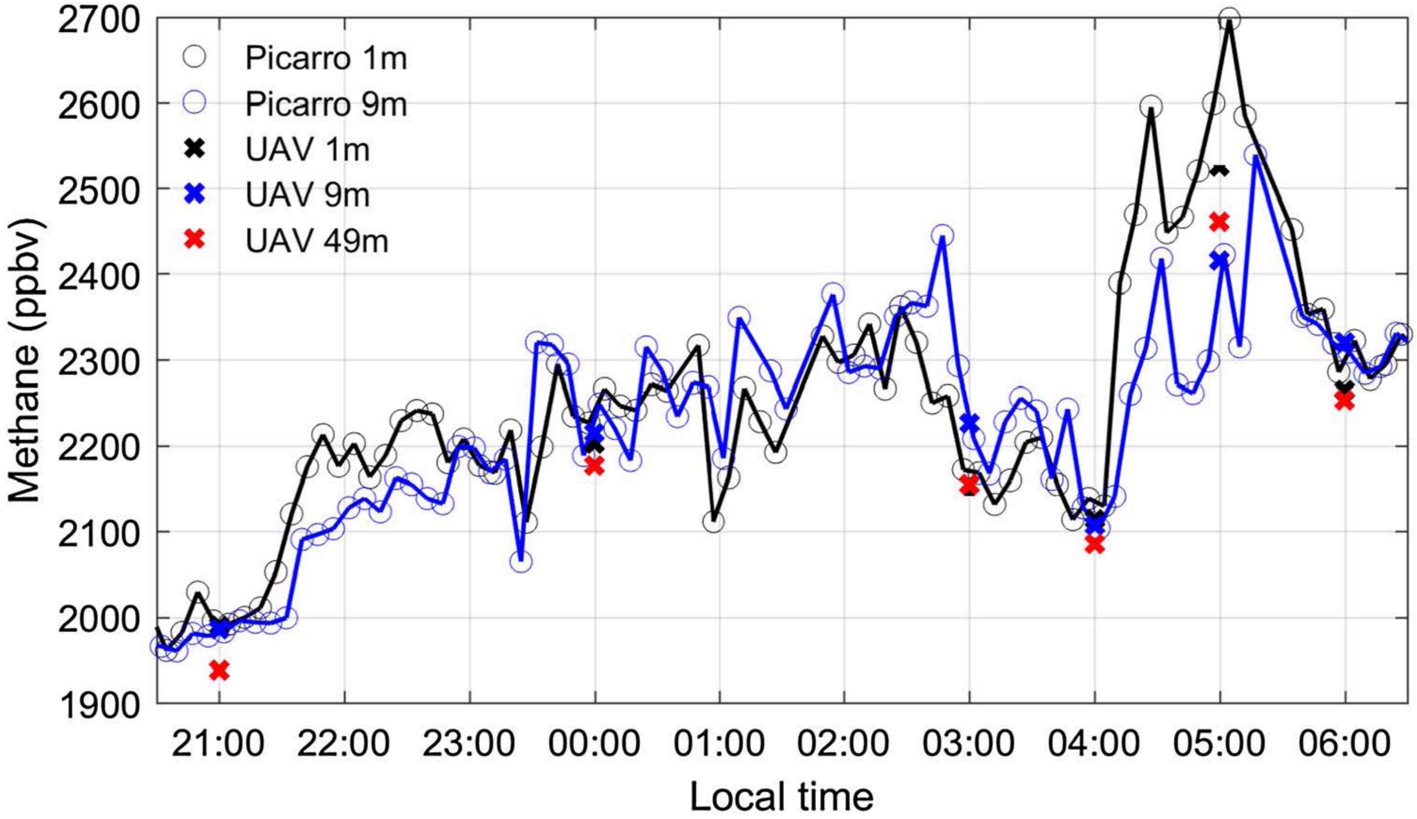

Figure 4. Methane levels measured by the Picarro-equipped tower (open circles connected by lines) and the hexacopter UAS (cross marks). The measurements at 1 m for both the tower and UAS are depicted in black, while the measurements at 9 m are shown in blue. An additional measurement from the hexacopter is shown in red.

WAVELENGTH SOLUTIONS

Unmanned aerial systems, as opposed to balloon flights or aircraft-implemented systems, have vastly reduced payload capacity. This required the researchers to develop a system that met these size and weight requirements.

Wavelength's LDTC0520 drove the laser and controlled the temperature for the precision laser system, and aided in the small footprint required for the system. With a size of approximately 6 cm x 7 cm x 3 cm, and a mass of 86.2 g, the LDTC0520 was able to fit both the small size and low mass requirements.

Additionally, the LDTC0520 offers the laser stability and laser safety features required for this application.

In order to have the high precision required, the laser being used for wavelength modulation spectroscopy needs to be controlled at a high level. This means that both a low-noise, high bandwidth laser driver and accurate temperature control is needed. The LDTC0520 meets both of these needs. With its long-term stability (up to 50 ppm over 24 hours) and modulation bandwidth (up to 500 kHz) specifications, the laser driver portion of the LDTC0520 was well-suited to drive the GaSb laser.

With temperature control accuracy of 0.008°C, the LDTC0520 was also able to maintain the temperature of the laser, ensuring stable output.

PRODUCTS USED
LDTC0520

KEYWORDS

unmanned aerial systems, UAS, wavelength modulation spectroscopy, WMS, mid infrared, laser driver, temperature controller, methane, atmospheric sensing

REFERENCES

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USEFUL LINKS

- LDTC0520 Product Page

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No changes were made to the figures, they are presented here in their original form.

All captions have been modified from their original form.

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REVISION	DATE	NOTES
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