INSIGHT M
METHANE MANAGED

Description of Technology

Insight M LeakSurveyor™

SUBMITTED TO

The United States Environmental Protection Agency
Air Emission Measurement Center (EMC)

SUBMITTED BY

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Description of Technology

Insight M LeakSurveyor™

Introduction

This document contains the technical description of the Insight M LeakSurveyor technology ("LeakSurveyor"), used for surveying for methane emissions at onshore oil and gas facilities. The following information is included:

I. Scientific theory underlying the LeakSurveyor technology
II. Description of physical instrumentation
III. Type of measurement and application
IV. Known limitations of the technology
V. Data inputs and workflow
VI. Data handling, storage, and delivery
VII. Validation of sensor performance
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This document is intended for public use. It is paired with the *Insight M Formal Alternative Test Method* document, which outlines deployment protocols.

I. Scientific theory underlying the LeakSurveyor technology

The Insight M LeakSurveyor detects methane using imaging spectroscopy, which is a methodology that collects ground-reflected sunlight and measures the absorption of infrared light. The spectral response of methane, as well as other atmospheric components such as carbon dioxide and water, have been well-characterized in laboratory settings (Gordon et al., 2022), and the detection and quantification of these spectral features underlies the general approach to remote sensing imaging spectroscopy (Raychaudhuri, 2016; Thompson et al., 2019). Several deployed airborne and spaceborne systems today use imaging spectroscopy, targeting a variety of remote sensing applications and spectral characterization, including the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) (Greene et al., 1998), the Hyperspectral Precursor of the Application Mission (PRISMA) satellite (Cogliati et al., 2021), and the Earth Surface Mineral Dust Source Investigation (EMIT) sensor currently onboard the International Space Station (Green et al., 2020). The LeakSurveyor spectrometer relies on the same set of principles as these systems. It detects the specific pattern of methane absorption of solar energy within its spectral range, which is targeted to avoid signal confusion from other gasses like carbon dioxide, water vapor, and ethane.

LeakSurveyor, along with all other remote sensing technologies that rely on reflected sunlight (generally referred to as "passive" imaging technologies), measures the total concentration of methane along the complete path of the light entering the instrument. This includes the entire atmospheric column that the sunlight must pass through to reach the surface of the Earth. Because methane is present throughout the atmosphere, detection of methane emissions represents areas where the measured amount of methane is above that of background atmospheric methane. Additionally, excess methane concentration in the field is assumed to be a result of both methane release rate and wind-driven dissipation of the methane plume.

II. Description of Physical Instrumentation

LeakSurveyor consists of multiple subsystems that enable the collection of actionable and accurate data.

- The imaging subsystem contains the infrared spectrometer and an optical (RGB) camera. The spectrometer data is used to detect methane, as described above. The optical camera collects imagery that provides a synchronous snapshot of the emitting facility, and can be used to both further pinpoint the emitting location and inform understanding of ground conditions at the time of airborne survey.
- The compute subsystem contains a flight computer, a GPS/INS system, and a WiFi router. The flight computer runs all of the embedded flight software, which controls both cameras and the GPS/INS unit. The GPS/INS system records a log of all positions and orientations of the LeakSurveyor system during its collection period. The computer also runs a suite of proprietary software which allows the pilot to operate and monitor the system remotely via the WiFi router.
- The power subsystem contains an FAA-approved battery and network-connected power distribution electronics which enables our flight software to control the power states of all the devices.
- The full system was patented on November 12, 2015, under International Patent Number WO 2015/172056 A1
- The external schematic for the pod is provided below. The total weight is 42 lbs.

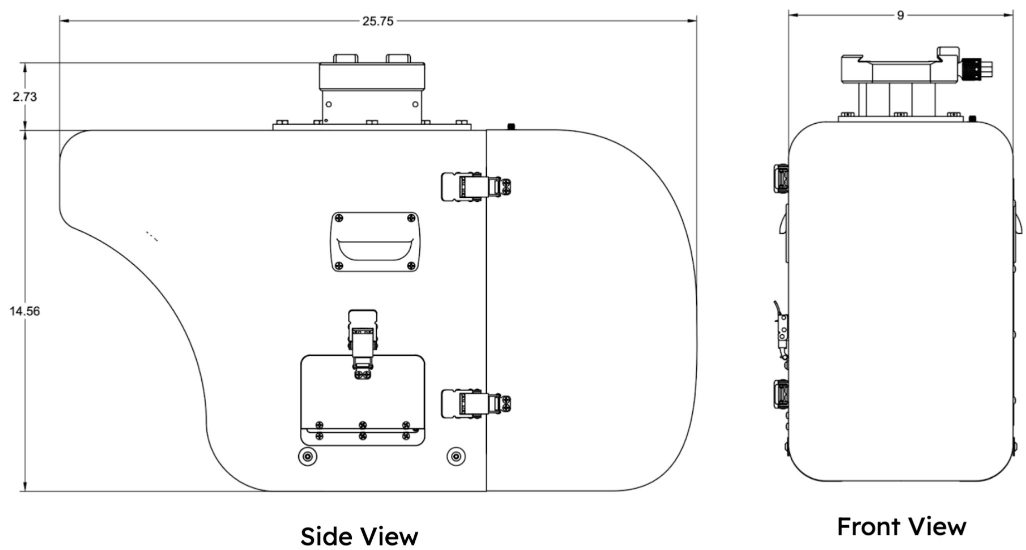

Figure 1: External schematic of LeakSurveyor pod.

III. Type of measurement and application

LeakSurveyor is an airborne-mounted remote sensing instrument capable of surveying any onshore oil and gas infrastructure for methane emissions. It is capable of identifying emissions to the facility level, as well as quantifying the amount of methane being emitted within a characterized range of error. Detection capabilities have been validated via third-party, blinded review (El Abbadi et al., 2024) as well as rigorous internal field testing.

IV. Known limitations of the technology

The Insight M spectrometer limitations are outlined in Section 4 of the *Formal Alternative Test Method* document.

V. Data inputs and workflow

A. Collected data

Transforming raw spectroscopic data, collected by LeakSurveyor, into geolocated methane plumes is done via the Insight M proprietary pipeline, which includes both automated and supervised analyses. The general procedure is summarized in the following processing steps:

- Raw methane data is automatically saved into a spatially-aware data structure and transformed into an estimate of methane enhancement.
- Methane enhancements are assessed by analysts and flagged if determined to be valid plumes.
- The source rate is automatically quantified for all valid plume detections.
- Valid methane detections are associated to their source. Multiple observations of a single source (resulting from multiple overflights) are grouped together into a single emission detection.

B. Meteorological data

Source and explanation of meteorological data
Weather, and specifically wind data, is an important input into the Insight M analytical pipeline. Given the geographic range of possible deployment and the sparsity of ground station wind data, we rely on third-party, numerical prediction models that ingest real-world data and incorporate them into physical meteorology models. This allows for a best estimate of wind over large spatial and temporal scales, even in remote areas where there may not be ground stations. Insight M evaluates weather providers for performance, as it is well known in emissions quantification that wind estimates can be a significant source of error.

Numerical meteorological prediction models typically share certain characteristics; they physically simulate the atmosphere by dividing it into “boxed” grid cells consisting of vertical atmospheric layers and horizontal grid boxes. Within each grid cell, real world data, when available, is incorporated, and relevant weather variables like wind speed, temperature, and cloud cover are computed by solving complex mathematical equations over a set spatial scale. Model considerations such as finer spatial and temporal scales are balanced against other considerations like computational time.

In some cases, third party meteorological providers' wind data are modeled at a height of 10 meters. To more accurately model wind conditions nearer to the surface (and the location of the methane source), we will scale modeled estimates via a power law scaling factor (Peterson et. al., 1978). This approach has been used for other methane emissions studies, as it enables better characterization of wind at the site (Sherwin et. al. 2021).

Use of meteorological data:
For each of the functions below, wind data is queried directly from the third party provider via an API.

- **Pre-Flight planning**: When drawing up survey plans, we use weather forecasts (including wind as well as other relevant meteorological variables) to determine whether conditions will permit safe aviation, compliance with FAA regulations, and operation within the LeakSurveyor operating envelope. See Section 4 of the *Formal Alternative Test Method* document for additional information on the LeakSurveyor operating envelope.
- **Data quality assessmen**t: Datasets are assessed for quality using a series of automated and manual checks. Wind speed may be used as part of an assessment of dataset sensitivity. If the sensitivity is above the target threshold, data is discarded and the area is re-surveyed. All queried wind data for this purpose is stored in a database.
- **Detected plume analysis**: Wind data is provided to analysts to assist with their assessment of a possible plume detection. Queried wind corresponds to the exact location and timestamp of each potential detection. All queried wind data for this purpose is stored in a database.
- **Emission rate quantification**: The Insight M analytical pipeline produces a wind-independent emission rate, generally provided in units of kilograms of methane per hour per meter per second of wind. In order to convert this to a true emission rate (eg, in units of kilograms per hour), this value must be multiplied by a wind speed estimate. For a more in-depth explanation of how wind is used for emissions quantification at Insight M, see our attached white paper, *Insight M Methane Emissions Quantification Methodology*.

C. Description of plume modeling used in the analytical pipeline

The LeakSurveyor analytical pipeline does not rely on plume modeling.

D. Description of machine learning procedures used in the analytical pipeline

The LeakSurveyor analytical pipeline does not rely on machine learning. Rather, physics-based models are used to extract an estimate of excess methane from a measured signal.

VI. Data handling, storage, and delivery

A. Data management and processing

Please refer to the *Insight M Formal Alternative Test Method* document, Section 11.3, which describes data management, processing, and storage.

B. Data streams provided to the end-user

For each validated emission detection, the data provided include, but are not limited to:

- Detection Time: The date and time of detection
- Emission ID: A unique identifier for the emission that allows for comparison with past and future reports

- Associated Asset: The name and/or ID of the facility where the emission was observed
- Location: The estimated emission location, based on the shape and extent of observed methane (reported as a latitude/longitude coordinate)
- Emission Rate: The best estimate of emission rate from the source
- Geolocated methane plume images superimposed on a geolocated optical image to guide close-range follow-up surveys
- If applicable, notes regarding the emission, such as suspected intermittency, notification of liquids leaks, notification of emissions in proximity of human occupied structures, observed maintenance events, etc.
- Date that emission result is made available to the operator.

For each contracted survey, Insight M provides additional coverage data to the client, including for surveys that yielded no confirmed emissions. The survey data provided include, but are not limited to:

- Confirmation that the alternative test method described in this protocol was the test method deployed by Insight M for the complete survey.
- Confirmation of the facility-level spatial resolution of the survey and the validated sensitivity of the deployment.
- Survey coverage results for each target site, provided as a cumulative list of coverage datetimes. Coverage results are provided for all target sites in a contracted survey, whether or not any emission was detected at the site.

C. Data delivery

Data is delivered in a digital format that is agreed upon with each individual customer. Final analyzed and validated detection data, including the attribute data listed above, is available within 1-5 calendar days.

VII. Validation of sensor performance

A. Independent evaluation of sensor performance

In October 2022, the Insight M LeakSurveyor was independently validated by Stanford University via a single-blinded controlled release test (El Abbadi et al., 2024; see Sherwin et al., 2021 and Rutherford et al., 2023 for peer-reviewed documentation of the testing protocol).

- Testing parameters: Over 5 days, the researchers tested a total of 191 validated controlled releases of varying emission rates to assess sensor detection, quantification, and false positive rate. A total of 107 of these releases were less than 15 kg/hr and an additional 18 were null releases (0 kg/hr) to determine false positive rate. Tested rates ranged from [0.64 - 1,110 kg/hr].
- Results: The full results of this test are published in the study manuscript, El Abbadi et al. (2024). In summary, testing assessed the performance of the Insight M LeakSurveyor, including sensitivity, false positive rate, and quantification accuracy:

- Sensitivity: The study reports that the largest missed detection was 10.47 kg/hr (representing the only missed detection above 10 kg/hr). The smallest detected plume was 3.4 kg/hr. A logistic regression fit to the study data demonstrates a 90% probability of detection of 8.9 kg/hr under testing conditions (see Figure 2 below).
- False positive rate: LeakSurveyor demonstrated a false detection rate of 0%.
- Quantification: Quantification accuracy was assessed with an r^2=0.87, with 38% of quantified rates falling within +/- 25% of the true flow rate, and 73% falling within +/- 50%. This is similar to performance demonstrated in the previous single-blinded testing of Insight M technology (Sherwin et al., 2021) which observed 1 sigma quantification error of approximately 40% (1 sigma).

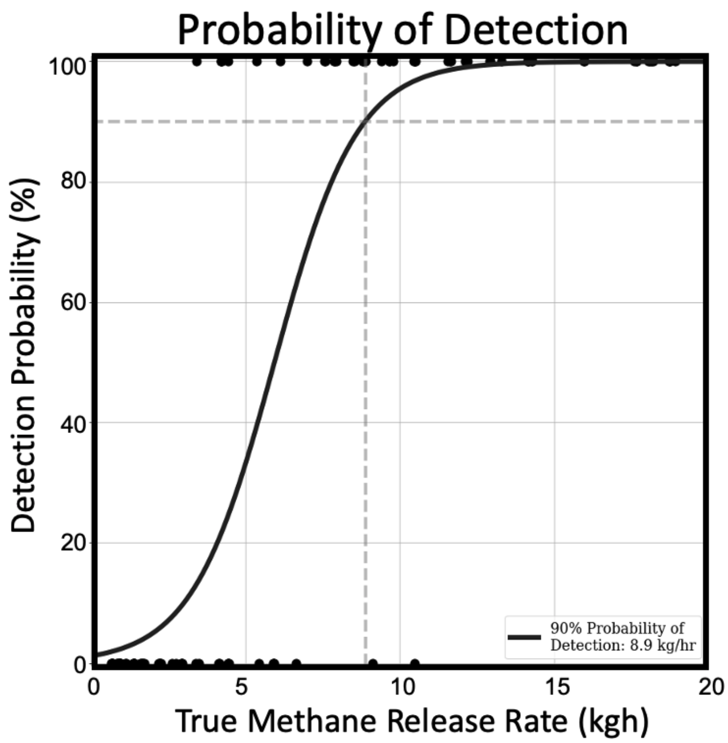

Figure 2: Probability of detection of the Insight M LeakSurveyor, calculated as the logistic regression fit to the data collected during single-blind testing by El Abbadi et al. (2024).

B. Evaluation of field sensor performance by Insight M

Insight M routinely conducts controlled releases to ensure that expected methane detection thresholds are maintained in the field. Controlled releases are designed to quantify performance across different axes of variability, including environmental conditions and deployment configurations.

1. *Summary of Insight M controlled release methodology*
Insight M follows a controlled release protocol similar to that described by El Abbadi et al. (2024) and Sherwin et al. (2021). In summary, the controlled

release procedure requires methane to be released at known rates from a fixed location while the sensor surveys the release area. Typical survey patterns are alternating direction passes along a single flight line. Methane flow rates are measured with 'in-line' flow meters which record the flow rate as well as the temperature of the gas as it is released with high precision. The site is also instrumented with an anemometer (wind gauge) which records local wind data with high granularity. Recorded flow rate data (including null passes where no methane is released) is compared against both detections and leak rates calculated from LeakSurveyor measurements processed through the Insight M analytical pipeline. Through this analysis, methane leak rate quantification accuracy, sensitivity, and false-positive rates can be calculated for a given sensor.

During a controlled release, LeakSurveyor is mounted aboard fixed-wing aircraft and deployed as it would be in the field. Prior to the start of the controlled release, a release plan is created that is designed to test the instruments' sensitivity, quantification accuracy, and false positive rate. Prior to the start of a pass, a specific release rate is chosen based on the recommended release rate from the release plan and current wind conditions. One minute prior to the plane's overhead pass, the flow rate is held constant in order to obtain a steady state flow downwind of the release point. Once the plane is overhead, the release rate, wind data, and any relevant notes are recorded by the ground crew. This process is repeated multiple times throughout the test to gather a range of representative data.

2. *Conditions required for testing*
   Insight M conducts controlled releases under a range of conditions and environments to determine the impact of environmental conditions on performance. Controlled releases are not conducted under the following conditions:
   - Meteorological or other conditions which prevent safe flight (i.e. dense fog, very strong winds, heavy rain)
   - High winds greater than 25 mph
   - Smoke or other fine particulate in large enough quantities to obscure local visibility
   - Nearby air traffic

3. *Safety*
   Safety can be split into two categories, ground crew safety and aircraft crew safety. Insight M practices error prevention via AESOP for both the ground and aircraft crews prior to any controlled release (see www.errorpreventioninstitute.com for additional information on the AESOP method).

   Ground crew safety:
   - Only licensed/qualified experts are allowed to manage the release of gas
   - Use of PPE
   - Over-pressure release valves on all volumes exposed to high pressure
   - Large distance between high pressure gas system and personnel

- Risk evaluation prior to pressurization
    - Checking high pressure gas lines for leaks or wear and tear
    - Assessing open sources of flame and sparking
    - Identifying trip hazards
    - Identifying and mitigating loud noise sources
- Additionally, methane gas is released into the atmosphere at rates below the point at which spontaneous combustion is possible. Diffusion from wind is strong enough to disperse any released methane.

Aircraft crew safety:

- Aircraft maintenance requirements must be met
- Safe flying conditions (IMC)
- Mechanical inspection of all Insight M instrumentation prior to installation on the aircraft

4. *Required equipment*

The following equipment is used for internal controlled release testing:

Gas Release Equipment:

- Methane gas trailer containing ~1,100 kg of methane. Between one and three trailers of methane are released by licensed and trained personnel into the atmosphere for each round of testing.
- Gas regulation system to step down high pressure gas prior to release
- Long high pressure hoses
- Release stack to emulate release from actual oil and gas facilities
- High pressure and low pressure gas regulators

Ground measurement instrumentation:

- Quadratherm inline gas flow meter 780i,
    - Measures flow range 30 - 1,150 kg/hr
    - Accuracy:
        - ±0.5% of reading from 50% to 100% of full scale
        - ±0.5% of reading plus 0.5% of full scale from 0% to 50% of full scale
- Sierra Instruments Mass flow controller C100H2
    - Flow control range 0.7 - 30.7 kg/hr
    - Accuracy ±1.0% of full scale including linearity under calibration conditions
- Tempest Weather System used to measure local wind data at the release site
    - Wind speed accuracy ±0.5 mph
    - Wind direction accuracy ± 5 degrees

Equipment used during controlled release testing is stored in a secure area and subject to the following calibrations:

- The flow controller and flow meter are factory calibrated from their purchase in 2022 and will be recalibrated by the manufacturer every two years.
- Portable weather stations are factory calibrated with a 10 year guarantee. Weather stations are replaced every 10 or fewer years.
- Each spectrometer goes through a set of lab based calibrations. See section 10 of the *Insight M Formal Alternative Test Method* document. Calibration is done prior to releasing a new pod for active deployment, and at regular intervals for pods already deployed to the field.

5. *Controlled release data storage and processing*
   Controlled release measurement data is collected using a flight computer, identical to the method deployed in the field. Data is then uploaded to a cloud storage solution for quick access and long term back-up. Ground data, including metered release rates and weather station data, is recorded by the ground crew and also captured by data loggers to ensure redundancy.

   Data is processed by the same analytical pipeline that is used to process field data, with the same data quality checks ensuring: 1) Proper collection conditions, including illumination and temperature; 2) Proper flight collection, including altitude above ground, yaw/pitch/roll of aircraft, and airspeed; 3) Proper sensor operation, including battery operation and operating temperature; 4) Flags in metadata indicating any issues encountered during telemetry; and 5) Flags in metadata indicating any additional issues encountered during data processing.

6. *Evaluation of sensitivity*
   Sensitivity is measured as a probability of detection curve, which is modeled based on controlled release data collected at a variety of sensor altitudes and across a range of wind speeds, from multiple overpasses that span a large range of possible emission rates (from very small to very large). This data is used to generate a functional curve following a method similar to Conrad et al. (2023). As the release rate approaches the instrument's sensitivity limit for a given altitude and wind speed, the probability of detection decreases from 100% to 0%. A function is fit which can model the combinations of sensor altitude and wind speed that will return a 90% probability of detection for a target rate.

   Please refer to the *Insight M Formal Alternative Test Method* document for further discussion of internal controlled release testing.

C. Standard operating procedures and deployment protocol

Please refer to the *Insight M Formal Alternative Test Method* document for a detailed review of the field deployment protocol.

Updating Training and Protocols. Regular protocol updates are essential for staying ahead of evolving challenges and ensuring optimal performance and safety. We continuously review and refine our protocols to incorporate the latest industry standards, technological advancements, and feedback from our team members. By staying proactive and adaptive, we uphold our commitment to excellence and safety in all aspects of our operations.

D. Additional documents provided to end users

New end users are provided with one-on-one support with a dedicated customer success representative to navigate any questions that may emerge before, during, or after a survey.

VIII. Validation of facility-level resolution

The Insight M LeakSurveyor includes an RGB optical camera within the pod unit, which is used to collect simultaneous optical imagery of all areas that are surveyed. During analysis, analysts are provided with this simultaneously collected optical imagery, as well as GIS data of oil and gas infrastructure and 3rd-party wind data, to verify the source of a detected and validated plume at the facility level. Analysts undergo a total of 9 to 18 weeks of training to become familiar with field data and the analysis task, including the step of facility-level association.

LeakSurveyor can also sometimes detect emissions at the equipment group level. For example, Figure 3 shows a single facility with three distinct plumes, which an Insight M client confirmed as three distinct emissions from different sources on the same pad.

Figure 3: Three confirmed emissions observed at a compressor station facility.

IX. Supplemental reading

A. *Insight M Methane Emissions Quantification Methodology*: White paper documenting the quantification algorithm used by the Insight M LeakSurveyor analytical pipeline.
B. El Abbadi et al. (2024): Single-blind study of LeakSurveyor performance.

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