Kuva Alternative Test Method Application

Formal Alternative Test Method

January 22, 2025

Submitted to:

US Environmental Protection Agency
Emission Measurement Center
Oil and Natural Gas Advanced Methane Technology Program
Research Triangle Park, NC

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kuva
Methane Mitigation Simplified

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Periodic screening method for Kuva GCI360

1. Scope and Application

1.1 Introduction
This document describes the method for deploying the Kuva camera based system for periodic screening surveys of oil and gas sites. The Kuva system is deployed as a stationary remote sensor capable of surveying all onshore oil and gas infrastructure. The Kuva system collects reflected sunlight and measures the total concentration of methane along the complete path of the light entering the instrument. It is capable of identifying emissions to the area level spatial resolution within a radius of 2m of the source. The detection capability has been validated via third-party, single-blinded testing (peer-reviewed and published), a large number of internal controlled release tests, and field performance in over a dozen oil and gas basins.

1.2 Scope
This protocol outlines an alternative test method using advanced methane detection technology for periodic screening for fugitive emissions and emissions from covers and closed vent systems in lieu of the procedures set forth in 40 CFR §60.5397b and §60.5416b(a)(1)(ii) and (iii), (2)(ii) through (iv), and (3)(iii) and (iv).

1.3 Instrument
The methodologies in this protocol are specifically designed to be applied with the Kuva GCI360 camera instrument and the Kuva cloud solution. Kuva is the sole producer of the Kuva camera and operator of the cloud solution. This document outlines the protocols employed for conducting a periodic screening for methane emissions.

1.4 Applicability
The methodologies described in this protocol are appropriate for detecting methane emissions from onshore oil and gas infrastructure. The methodologies are broadly applicable to all onshore oil and gas emission sources in the United States. The Kuva GCI360 camera instrument described in this method specifically detects both Methane and volatile organic compound (“VOC”) plumes corresponding to elevated concentrations of methane or VOC gas.

1.5 Spatial Resolution
Deploying the Kuva system according to this protocol characterizes emissions at an area-level spatial resolution within 2m radius of the source.

1.6 Sensitivity
The deployment of the Kuva system described in this protocol will achieve a 90% probability of detection of an emission source that is emitting methane at a rate of 15 kg/hr at a distance of 100m from the camera mounting base. The presence of VOC emissions in conjunction with methane and the detection of emissions at shorter distances than 100m significantly improves the effective site detection sensitivity and thereby improves the probability of detection.

2. Summary of Method

The method requires the use of a Kuva GCI360 camera instrument, the Kuva cloud solution as well as a tower / pole, power supply and data connectivity for the camera.

The key Kuva system components are illustrated in Figure 1 below. Details are described in section 6.

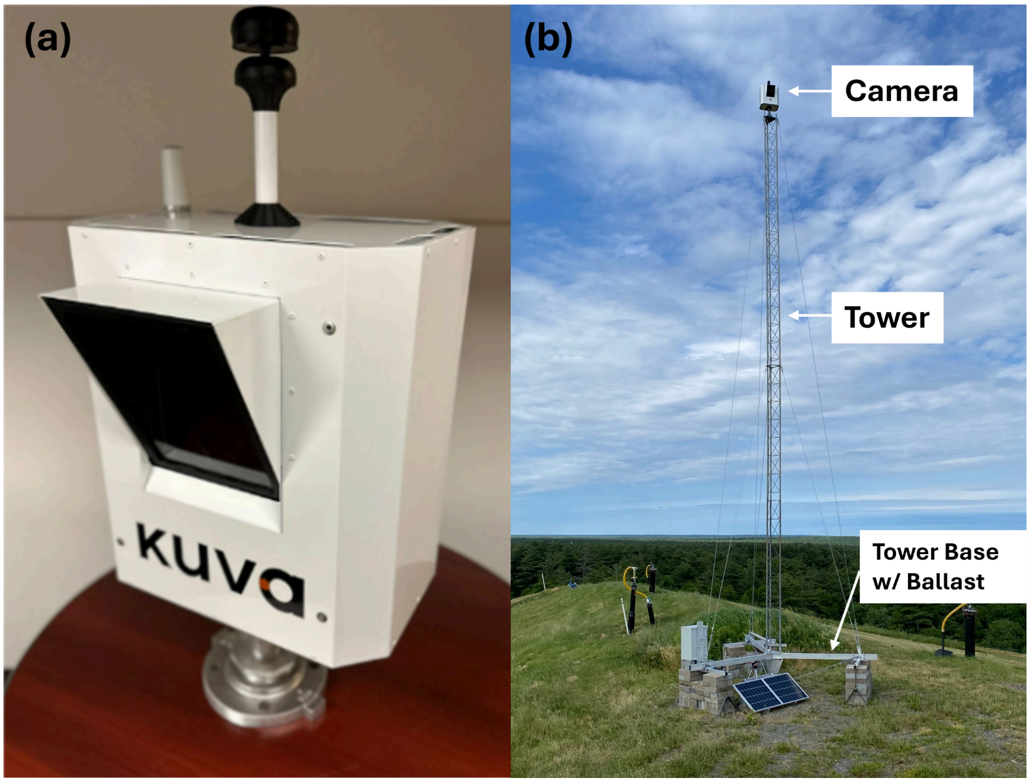

Figure 1: (a) Closeup of the GCI360 camera with integrated ultrasonic anemometer and LTE antenna, (b) A Kuva GCI360 installed atop the optional 40-foot Kuva Tower with ballasted base and guy wires for increased stability.

The Kuva GCI360 camera is based on a single pixel detector. In order to collect one image the Kuva GCI360 camera moves in an x-y scan pattern using an integrated pan-tilt system and covering a vertical field of view of 54 degrees and a horizontal field of view of 46 degrees. Up to 8 fields-of-view can be defined allowing coverage of up to 360 degrees.

The scientific principles and underlying physics of the gas detection of the Kuva System are based on imaging spectroscopy in the Shortwave Infrared (SWIR) portion of the electromagnetic spectrum. This principle is widely used in aerial and satellite-based solutions for methane emissions detection as well as gas safety equipment for the oil and gas industry, such as open path detectors. In addition, the Kuva System contains a visible RGB camera that takes a color image together with each infrared image.

Data is processed inside the GCI360 Camera, and processed infrared and visible images generated in the camera are uploaded to the Kuva Cloud Solution, where they are screened to eliminate false positive detections. After this false alarm screening, emission events (if any) are automatically generated by the Kuva cloud solution and the results of the periodic screening (irrespective if emissions are detected or not) are transmitted to the operator.

The method performance can be affected by factors such as distance, the absence of sunlight, precipitation, cloud cover, background reflectivity and high wind speeds. The distance for this method is limited to a 100m radius around the camera installation point. In order to ensure that the periodic screening is conducted within the environmental conditions suitable for detecting methane emissions at or below 15 kg/h, the camera is utilizing a Detection Capability Score that is dynamically calculated based on the SWIR light signal received at the camera and the wind speed and direction measured by the anemometer connected to the camera.

At the 1st of every month or every other month (depending on the requirements for the applicable site type) the camera automatically enters the periodic screening mode. The screening is conducted using five successive images for each field-of-view and only if the average detection capability score for these five images meets or exceeds a threshold value. The collected images are then processed for gas detections, uploaded to the Kuva cloud, screened for false alarms and transmitted to the operator.

3. Definitions of Method

*API***:** Application Programming Interface used to exchange data between multiple cloud solutions.

Confirmed detection: Once an emission event is being received by an operator, it is reviewed by visual observation by the operator to determine if the emission event constitutes an “allowable emission” or a “confirmed detection” (i.e fugitive emissions or emissions from covers and close vent systems).

Detection candidate: An infrared image with a possible methane detection autonomously triggered by detection algorithms running inside the Kuva camera. Detection candidates are sent to the Kuva cloud for screening as a true positive or false positive.

Detection Capability Score: A numeric value from 0-1 representing the instantaneous, local conditions and their impact on the probability of detecting a given emissions rate of hydrocarbons within the field of view of the image.

*Emission event***:** Once a detection candidate has been confirmed as a true positive through the cloud based false positive screening, it is classified as an emission event. The emission event is then transferred to the operator for review.

GIF: Graphics Interchange Format, a bitmap image format that allows for the visualization of a series of images as video-like animations by playing multiple images in successive order and allowing to present them repeatedly by looping.

MQTT: a standards-based messaging protocol used for machine-to-machine communication in the oil and gas industry for process sensing and automation.

SWIR: Short Wave InfraRed portion of the electromagnetic spectrum

VOCs: Volatile organic compounds

4. Interferences

The Kuva GCI360 camera operates under almost all conditions prevalent in US basins, including temperature ranges of -40°C (-40°F) to +50°C (122°F), 0 to 95% non-condensing relative humidity, and snow covered ground. Because the camera relies on receiving SWIR from sunlight, operation is limited to daytime and times of sufficient SWIR light being present.

The Kuva System is a multispectral system that detects both methane and other hydrocarbon emissions around the 2.3um band based on absorption spectroscopy. The Kuva camera does not have cross-sensitivity or interference from water vapor, CO2 or N2. The camera does have limited cross-sensitivity to ammonia gas. Ammonia is toxic and is rarely if ever present at upstream or midstream oil and gas sites. The camera does not detect heat signatures, does not measure temperatures of gas or objects ("Delta-T") and has no cross-sensitivity to hot exhaust.

The following list of parameters can affect the detection capabilities of the camera:

1. Line of sight
The camera measures the path-integrated methane concentration, typically expressed in parts per million times meters (ppm-m) along the light beam. For such measurements, the light beam must reflect off background scattering surfaces and pass through the plume of methane. If the plume is completely obstructed from the camera's line of sight by equipment or structures, the beam will not pass through the gas. The camera can measure methane emissions that are at least partially in the direct line of sight of the camera. The system need not have a fully unobstructed view of all parts of a facility in order to detect emissions, as gas plumes can be detected as they emerge from behind an obstruction. To mitigate line-of-sight issues, the camera is mounted on a mast or existing equipment taller than the equipment to be monitored to get a vantage point.

2. Insufficient SWIR illumination received by the camera
For the camera to detect emissions it needs to receive sufficient infrared illumination emitted from the sun. To be received by the camera, the light beam needs to be reflected off a background. Both reflective and diffuse surfaces work as a background object. Common real world reflecting surfaces including ground, buildings and structures, vegetation, etc. An exception is water as it absorbs shortwave infrared light. In general, onshore oil and gas facilities do not have standing water surrounding the equipment.
Situations of insufficient infrared illumination occur during heavy precipitation (rain, snow, sleet, fog, etc.), thick cloud cover, at night, with standing water as well as with shadows. To mitigate issues with insufficient shortwave infrared illumination the camera continuously monitors the

amount of SWIR light received and no periodic screening is performed when insufficient SWIR light is received by the camera (see section 11.2).

3. Extreme wind conditions
At high wind speeds, smaller emissions are sufficiently diluted by the air flow to make them more difficult for the camera to detect, resulting in less obvious visualization. To mitigate issues with high wind speeds the camera continuously monitors the wind speed and no periodic screening is performed when the wind speed is unsuitable (see section 11.2).

4. Hydrocarbon Interferences
The Kuva System directly measures gas absorption tuned to hydrocarbons in the shortwave infrared around 2.3um. The system therefore measures both methane as well as hydrocarbon (VOC) emissions. While methane and VOCs are usually co-emitted at oil and gas sites, it is possible that only VOC emissions are present and may generate an emission event. Moreover, the system occasionally creates detection candidates that contain false detections based on thin objects made of hydrocarbons (e.g., plastics and polymers) and certain types of glare spots, as these tend to reflect and absorb sunlight similarly to hydrocarbons. Typical examples are windsocks, flying plastic bags, and glare spots on surfaces painted with hydrocarbon-based paint and corrugated metal. To mitigate issues with hydrocarbon interferences, detection candidates generated by the Kuva camera are screened for false positives in the Kuva cloud.

5. Safety

The Kuva GCI360 camera is an automated system that does not require regular on-site personnel, minimizing the safety risks typically associated with standard field operations for inspection based emissions monitoring. The two main safety risks related to this method are installation and presence of equipment onsite. The sections below describe the safety risks associated with both.

5.1. Installation and Maintenance

The main safety concern related to the camera is the support structure required to elevate the camera to a sufficient height. Camera installation procedures and rare on-site maintenance procedures carry comparable safety risks to other activities at oil and gas facilities like the installation of floodlights, security cameras or microwave communication towers. These risks include exposure to hazardous gasses such as methane and other toxic substances. Following all site specific safety protocols during installation and maintenance activities mitigates these risks. This begins with thorough hazard assessments before starting any field work. Ensuring all personnel are equipped with appropriate personal protective equipment (PPE) is also essential. This includes gas detectors, fire-resistant clothing, hard hats, safety glasses, and gloves. By adhering to industry standard safety measures, the risks associated with installation and maintenance activities in oil and gas facilities can be significantly reduced, ensuring the safety and well-being of all personnel involved. Moreover, Kuva offers an optional tower for the camera (see Figure 1 above). The Kuva tower allows for installation of the camera onto the tower while lying sideways. The tower is then raised to the vertical position using a hand winch. This eliminates the safety risk of working at heights, reduces equipment needs and speeds up installation speed and time on site.

5.2. Presence of equipment onsite

The presence of monitoring in the system installed on the site can introduce safety risks, such as:

- Traffic obstruction
- Structural Hazards
- Electrical Hazards
- Fire and Explosion Risks

These risks can be addressed by following industry standard engineering and operating practices applicable for oil and gas sites. Risk of traffic obstruction is addressed by a suitable camera placement. Structural hazards are addressed by the use of a mounting structure that is suitable for the respective wind rating applicable to a site and by installation following instructions. Electrical hazards are addressed by following industry standard work practices in connecting power and data to the camera. The Kuva camera is not designed or rated for use within hazardous areas where combustible or flammable concentrations of gasses may be present. However, these areas may still be monitored by the camera as long as the camera and support equipment are located in a safe area.

6. Equipment and Supplies

The key Kuva system components are illustrated in Figure 1 above. The components that make up the system can vary depending on the context of the installation, especially the tower/pole, power supply, and data connectivity. For example, masts can have different heights. The Kuva GCI360 Camera can be mounted to different structures with an attachment, power can be provided by site power or solar power, and communication can be provided externally or by an integrated cell modem. Therefore, the following description is for reference only.

The equipment and supplies consist of the following elements:

- **Kuva GCI360 camera** - The camera is a highly integrated solution that includes a proprietary shortwave infrared sensor and infrared optics, integrated tilt functionality, a 5MP visible RGB camera, an integrated processing unit, an integrated pan stage, an ultrasonic anemometer (mounted on top of the camera) for wind speed and direction measurement, power-over-ethernet connection, ethernet data output (via power over ethernet) as well as optional LTE modem and cell antenna.

- **Mast/tower -** The tower (sometimes referred to as a “mast” or “pole”) provides the support structure for the camera and for the routing of the ethernet cable from the ground to the camera. It is typically 40’ high and capable of withstanding high wind speeds. The tower may incorporate guy wires that can be secured to the foundation of the tower to minimize the footprint and eliminate the need for ground penetrations. Other tower variations may be used to support the Kuva camera as well as existing structures, like utility poles. Kuva offers an optional tower for mounting the GCI360 camera, which allows for fast installation.

- **Power Source** - The Kuva GCI360 camera is powered by 24V DC via power-over-ethernet. Power is provided either by a solar installation with battery backup (typically at the base of the pole) or by a connection to site power, if available. Power is routed via an ethernet cable from the bottom of the pole to the camera. The power consumption of the Kuva camera including all integrated accessories is approximately 25 watts.
- **Data via Ethernet** - In cases where the operator prefers to use locally available data connectivity or when no cell data is available at a site, site data connectivity is connected to the camera via a power-over-ethernet injector and then connected to the camera via the same ethernet cable that also provides power.

As the Kuva GCI360 Camera is a highly integrated system that comprehensively incorporates functionality in one device, no other functional components, such as an external gateway, external pan stage, external anemometer, etc. are required. As a result, installation and commissioning are comparatively straightforward and fast. The high degree of integration also minimizes the potential for installation errors and related malfunctions. The camera rotates around its own axis to scan each field of view using the built-in pan stage. No external tilt stage is required as the camera has an integrated tilt function generating a 54-degree vertical field of view.

7. Reagents and Standards

This method is executed using instrumentation that does not require reagents or standards.

8. Sample Collection, Preservation and Storage

This method does not require the collection of samples.

9. Quality Control

The following quality-control measures are implemented throughout the system to secure the ability to consistently implement a quality periodic screening. Quality-control checks of the system include the

- camera operation (ensuring the camera is operational within standard parameters and periodic screening is only performed under suitable environmental conditions),
- data transmission (ensuring security and no losses),
- cloud operation (ensuring all data are processed without failures and transmitted to the operator at the completion of each periodic screening), and
- camera manufacturing process (adhering to all quality requirements).

9.1. Camera operation

The GCI360 Camera is designed to operate over ambient air temperatures from -40°C to +50°C. To ensure the quality of camera operation, the Kuva Cloud Solution monitors the performance characteristics and health of the camera systems and generates alarms in case of malfunctions. Device telemetry is automatically logged by the camera. Parameters monitored include the quality of the data connection, the voltage level of the power supply, the temperature of the internal infrared detector and connection status to the anemometer.

In the case of loss-of-power the camera automatically restarts and performs a homing procedure upon power becoming available again to re-establish its rotational position and then resumes normal operations. In the case of data connectivity loss, the GCI360 Camera continues to operate, storing up to ten days worth of image data in its internal memory. If the internal memory is full, any data related to the periodic screening mode is retained and data related to the custom operating mode is overwritten and the camera continues to operate normally. Data is automatically forwarded to the Kuva cloud solution once data connectivity is restored. Data is deleted from the device only once it has been confirmed to be uploaded. The InGaAs sensor technology and related temperature control used in the camera is well established and widely used in the oil and gas industry for infrared gas safety detectors (point and open path sensors). InGaAs-based sensors are semiconductor devices that do not experience meaningful degradation with time or use and they are regularly used for 10 years or longer for safety critical applications in the oil and gas industry in harsh environments and without any maintenance. In the case of an abnormal reading of the temperature of the internal detector or in case connectivity to the anemometer is lost, an error is generated and transmitted to the operator and to Kuva to initiate a camera inspection and if necessary a replacement.

A Detection Capability Score is utilized to ensure that periodic screening data is only collected once suitable weather conditions are present. See section 11.2 for details.

9.2. Data transmission

All data in transit from the camera to the cloud is protected using encryption of the transmitted data. In case of communication failures interrupting the flow of data between camera and the cloud, the camera buffers data related to periodic screening until communication is restored, increasing the resiliency of the system to mobile data outages or intermittent communications in remote areas.

9.3. Cloud operation

Data is stored in the cloud in encrypted databases. “Detection candidates” are screened in the cloud for false positive detections before transmission to the operator. All raw, intermediate, and processed data are regularly backed up.

9.4. Camera manufacturing

Manufacturing follows manufacturing assembly and test steps based on written documentation. Parametric data collected during testing of subcomponents and complete cameras is stored in a Quality Management System, enabling statistical analysis and the monitoring of process deviation and continuous improvement. Critical components including infrared detector and printed circuit board assemblies (PCBAs) are functionally tested before assembly into a camera.

The test methods and limits are performed on custom test fixtures to ensure robust and reliable assessment of performance before assembly.
Validated parts are assembled into a camera housing, using detailed instructions and visual inspection points. Manufacturing calibration parameters are established and stored in the camera and recorded in a database. The assembled camera performance is assessed both for general functionality as well as for gas detection performance against pass/fail parameters with results stored in a database.

10. Calibration and Standardization

Factory calibration of the Kuva GCI360 Camera sensors is performed during manufacturing. All calibration testing is conducted as pass / fail against standard thresholds. The test readings are stored in a Quality Management System for each GCI360 Camera.

After initial factory calibration, the GCI360 Camera does not require field calibration or baseline data collection and can begin operation immediately after installation, initial power-up and setting of fields-of-view. The GCI360 Camera features integrated and automatic self-calibration of the infrared sensor multiple times per day. The temperature of the integrated detector is automatically maintained at the setpoint temperature, ensuring optimal detector sensitivity across the full range of rated ambient operating temperatures.

Installation is described in Section 11. As part of installation the fields of views are set based on a panoramic scan of the visible RGB image. The fields of view are stored inside the camera relative to a mechanical stop of the pan stage that is integrated inside the pan stage. In case of power loss, the rotational position of the camera is reestablished automatically in a homing procedure to the mechanical stop of the pan stage which allows for automatic resumption of operation at the pre-programmed fields of view. Because of the integrated mechanical stop there is no requirement for a calibration of installation geometry.

11. Procedure

The procedure to conduct a periodic screening with the Kuva system consists of two parts:

1. Installation and commissioning
2. Periodic screening

11.1. Installation and commissioning

Prior to the deployment of a Kuva camera, a site evaluation based on overhead imagery, a site plan or equivalent data is conducted to determine the location of the Kuva camera to be installed. For a potential camera / tower position on the site, each potential leak source is considered to ensure that it is within 100m range of the vertical axis of the Kuva camera and within the 54 degrees vertical field-of-view. The installation location is also chosen subject to safety and operational constraints at the site such as ensuring the installation does not obstruct truck traffic. Distance from the vertical axis of the Kuva camera to the farthest equipment to be monitored is validated to be at or less than 100m by the camera installers using a laser distance measurement tool, tape measure or a similar suitable instrument or a suitable site plan. In cases where the Kuva camera cannot be placed such that all equipment to be monitored is within a 100m radius, additional camera(s) are installed until such equipment is within 100m range or such out-of-range equipment is covered by conventional OGI inspections, EPA Method 21 or other approved Alternative Test Methods. The camera is mounted on a support structure. The camera is typically mounted at an elevated position, resulting in a good line of sight over the facility. One option for a support structure is for the camera to be mounted on a tower that is provided by Kuva and that can be installed by two people without any special heavy equipment (no crane required).

The Kuva System collects data for up to eight field-of-view segments of 46 degrees horizontal each. Data collection for each field-of-view is conducted in a raster scan pattern, pixel by pixel, and data is combined into an image. The field-of-view segments are fixed to 46 degree horizontal each but can be freely chosen in their pan position up to 360 degrees of coverage (i.e. 8 fields of view). They can be adjacent to each other, partially overlapping or separated. Due to the large 54 degree vertical field of view, no vertical adjustments are required. The image collection rate of a Kuva GCI360 camera is under 30 seconds per 46-degree horizontal field of view.

The physical installation is carried out by Kuva field service employees, by operators, or by qualified third parties. After the installation, a commissioning procedure is performed to ensure that the Kuva system can upload images to the Kuva Cloud Solution. During this procedure, a panoramic 360-degree visible RGB image of the site is captured by the camera. This panoramic image can be accessed via the Kuva Cloud Solution on a laptop or mobile device, and it is used to select and program the desired fields of views to ensure coverage of all components, covers and closed vent systems to be monitored. Additionally, geographic coordinates of the camera, timezone, and scanning schedule (activation of monthly periodic screening mode as per this work practice) are set up during this procedure.

For sites such as compressor stations with equipment subject to LDAR requirements located inside enclosed buildings, coverage of these enclosed buildings with a Kuva camera is not applicable. Such equipment inside buildings must be inspected with OGI or EPA Method 21 at the applicable inspection frequency for a given site. Buildings or equipment where compliance with environmental regulations is covered only with an OGI or EPA Method 21 inspection (i.e., enclosed compressor buildings) are not considered when determining Kuva camera placement.

11.2. Periodic screening

On the first day of every month or every other month (depending on the requirements for the applicable site type) the camera automatically enters a periodic screening mode where the camera calculates an average detection capability score for five successive images in a single field-of-view and evaluates whether this average detection capability score for these five images meets or surpasses a preset minimum threshold. If the threshold is met or exceeded the collected data is used to determine if emissions are present in any of these five images (detection candidate). The results for all five images (irrespective of presence of detection candidates) are uploaded to the Kuva cloud for false-positive screening. After false positive screening of any detection candidates, all five images for a given field-of-view are transmitted to the operator. The images are transmitted irrespective of the presence of any true positive detections as the absence of detections is equally important and it documents that the screening has been conducted. The operator receives the images and reviews images with true positive detections to determine if detected emissions are allowable (such as for example compressor methane slip) or if the images constitute a “confirmed detection” as per the OOOOb/c regulations (i.e. fugitive emissions or emissions from covers and close vent systems). Subsequently, the processes defined in the OOOOb/c regulations for “confirmed detections” apply.

After the image collection for the first field-of-view has been completed, the first field-of-view is recorded as “screened” inside the camera and the camera rotates to cover the next field-of-view, following the same process described above. If the detection capability score does not reach the minimum threshold for any field-of-view, the camera also moves to the next field-of-view, however the skipped field-of-view is <u>not</u> recorded as “screened”. When the last field-of-view is reached, the camera resumes with the first field-of-view that has not yet been recorded as “screened”. The process repeats until all field-of-views have been successfully recorded as “screened”, all images have been uploaded to the cloud, screened for false positives and transmitted to the operator.

By way of illustration, if on the first day of a month a storm occurs with high wind speed, the Kuva camera will remain in periodic screening mode and continue to scan until the weather improves and the detection capability score for the collected images meets or exceeds the threshold value (for example on day two of the month).

In case of loss of data connectivity, the camera will continue to function as programmed and the collected data will be stored on the camera until data connectivity is restored. In case of a malfunction that prevents the camera from collecting data at the first day of the month, the periodic screening mode will be entered automatically upon resumption of normal camera operation.

In case data for a successful periodic screening for a field-of-view has not been received by the Kuva cloud from the camera within seven days before the end of a month (either due to an extended camera malfunction or in the very unlikely case of a very long stretch of bad weather), the cloud solution will send a notification to the operator (for example by email, MQTT or via API), informing the operator to plan for a substitute OGI inspection for the given month for all equipment was not covered by a successful screening.

Upon completion of the periodic screening the Kuva camera can optionally be used by the operator for other monitoring purposes and can be programmed to operate depending on an oil and gas operator's needs. On the 1st calendar day of the following month (or bi-monthly, depending on the site-specific requirements) the camera automatically returns to the periodic screening mode and the process repeats.

12. Data Analysis and Calculations

Methane detection with the Kuva GCI360 is based on imaging spectroscopy. Each pixel of an image collected by the camera contains multiple spectral bands of information. Detection is based on multiple photosensors with spectral filters. At least one spectral filter is tuned to absorption features outside the absorption of methane, hydrocarbons, and water vapor and provides reference information. At least one spectral filter is tuned to absorption features of methane and hydrocarbons in the 2.2 to 2.4um shortwave infrared band and provides signal information. By comparing signal information with reference information, a differential absorption spectrum is generated that is proportional to the amount of hydrocarbons present. Column density is computed based on the factory calibration of the detector and the known spectral absorption of hydrocarbons at the spectral wavelength in question. Due to the use of a reference band, the Kuva GCI360 camera does not require an integrated gas cell.

In order to generate an infrared image for a given field-of-view, the GCI360 Camera features integrated pan and tilt stages with full control of the slow and fast-axis sampling, respectively. The raster scan is conducted in a zig-zag pattern, as shown in Figure 2 below. The horizontal scan speed is approx. 2° per second. The scan speed for a 46-degree field-of-view is approximately 26 seconds.

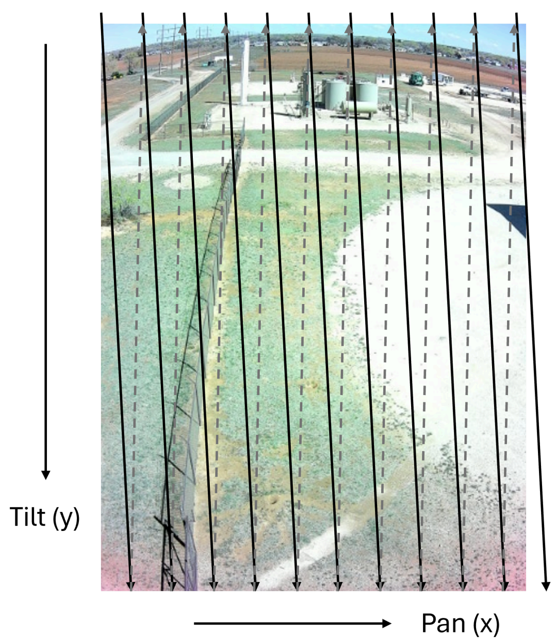

Figure 2: Raster scan pattern employed by the Kuva GCI360 Camera. Full field of view is 46° (H) x 54° (V)

The collected pixel-by-pixel infrared data is represented in a rectangular image format representing 46 x 54 degrees. The generated infrared image is then automatically processed inside the camera by applying a plume detection algorithm that identifies and separates out regions of elevated hydrocarbon presence. Once a plume is identified, it is visually represented with color coding representing different levels of column density for each pixel. Readings with gas detections are converted into images of gas based on a color scale where colors towards the red spectrum indicate higher column density and colors towards blue indicate lower column density. For an image to be created, the gas does not have to be blown to the camera, as the camera is a standoff detection solution. If hydrocarbon gasses are identified as present in an infrared image, the image is labeled as a “detection candidate”. Any amount of hydrocarbon emissions present - as low as 0.25 kg/h - generates a “detection candidate”. This method does not utilize a lower level “cut-off value” based on emissions quantification or based on duration. A detection of emissions in one out of the five images is sufficient. An example of an infrared image with plume overlay next to the corresponding visible image is shown in Figure 3.

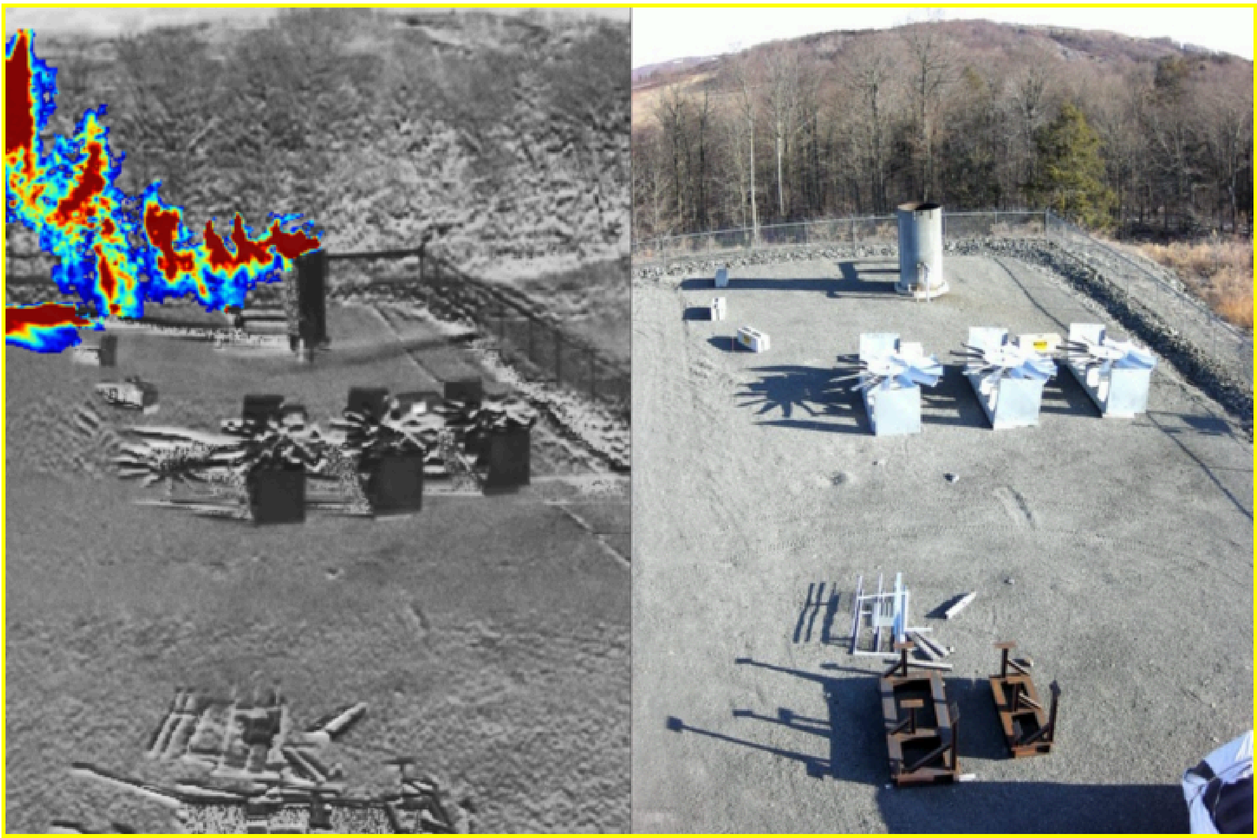

Figure 3: Infrared and visible image of a methane detection

During the periodic screening mode up to 40 infrared images are uploaded into the cloud (5 per field of view each for up to 8 fields of view). If any of these 40 infrared images have been tagged as a detection candidate during gas detection image processing, they are screened in the Kuva cloud for false positive detections. If one or more images are determined to be a “true detection”, then the image is tagged as a “detection event” in the cloud.

After the false alarm screening (if any) is completed, two image sequence files (.gif) are generated for each field of view, one with five greyscale infrared images (including plume overlay, if any) and one consisting of the five corresponding visible RGB images collected. The .gif files contain a timestamp as to when the periodic inspection was conducted. Data transmission of all .gif files to the operator happens automatically as soon as the false alarm screening and file generation has concluded. The .gif files are transmitted to oil and gas operators by email, API, MQTT, or similar methods, depending on the operator's preferred communication method. In case, there is at least one image with a detection event in the transmitted .gif file the operator is also informed about the presence of a detection event separately by email, API, MQTT, or similar methods. In case no detection events are generated, the operator may store the .gof files as proof that the periodic screening has been conducted and that no detection events have been found.

13. Method Performance

The detection sensitivity is dependent on distance to the source, wind speed and on the amount of shortwave infrared illumination received by the camera. The Kuva system detects 14.8 kg/h methane with 90% probability under conditions of wind speed, wind direction and infrared illumination received at the camera in combinations that are represented in the Detection Capability Score limit that is stored in the camera. This detection performance has been validated in blind testing at Texas Tech University. For installations at a site a 100m distance represents a 200m diameter as the camera rotates 360 degrees around its own axis.

In a real-world installations the effective average detection limit performance under this method is expected to be far better than 15 kg/h methane for three reasons:

1. Shorter detection distances
2. Detections below 90% PoD
3. VOC content

1. Distance

Detection capability improves significantly at shorter distances. In installations at typical upstream and midstream sites almost all equipment is located much closer to the camera than 100m distance. The Kuva system participated in testing at an average of 20m distance in ADED testing at METEC, where a minimum detection limit (MDL) of 0.25 kg/h and a 90% probability of detection of 3.5 kg/h was established in a 5-month blind test in weather conditions in Colorado and utilizing an older detection algorithm. With Kuva’s current detection algorithm the 90% PoD at 20m is approximately 2.2 kg/h methane.

2. Detections below 90% PoD

As shown in METEC testing the Kuva camera is capable of detections as low as 0.25 kg/h methane. During period screening five images for every field of view are collected. If any one of these images contains any amount of detectable methane (as low as 0.25 kg/h), and the detection is confirmed by subsequent false positive screening, a “Detection event” is created and submitted to the operator.

3. VOC content

The Kuva camera also detects other hydrocarbon gas emissions (VOCs). For example, the SWIR absorption strength of propane is about 90% of the absorption strength for methane, across the same wavelengths. As VOCs are usually co-emitted with methane the effective detection limit as attributed to methane only will be significantly more sensitive. Emissions from closed vent systems and covers (i.e. tanks) in particular have significantly elevated VOC content and will thereby be detected much more often than expected by the methane PoD curve alone.

14. Pollution Prevention

The method does not require a specific pollution prevention protocol. No physical samples are collected, which avoids generating waste. Additionally, the method reduces regular site visits, reducing transportation-related emissions compared to traditional inspection methods.

15. Waste Management

No physical samples or waste are generated in this procedure.

16. References

1. Waxman, A. M., Bylsma, J. M., & Vaitses, A. (2019). Scanning IR sensor for gas safety and emissions monitoring (United States Patent US10436710B2).
2. Bell, Clay, et. al, Performance of continuous emission monitoring solutions under single-blind controlled testing protocol, https://doi.org/10.1021/acs.est.2c09235. Solution “J” in the publication.

17. Tables, Diagrams, Flowcharts and Validation Data

N/A