Kuva Alternative Test Method Application

Description of Technology

Date

January 22, 2025

Methane Mitigation Simplified

www.kuvasystems.com

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1. System description

1.1. Overview

The Kuva methane emissions continuous monitoring system (the Kuva system) is a camera-based technology that has been available commercially since July 2021. This section provides an overview of the functionality of the system and the workflow of the Kuva system for periodic screenings. When deployed as described, the Kuva system achieves a 90% probability of detecting methane emissions at a rate of 15 kg/hr or below, meeting the minimum detection threshold for monthly screening specified in Tables 1 and bimonthly screening specified in table 2 of Subpart OOOOb of Part 60.

The Kuva GCI360 Camera is shown in Figure 1(a). It monitors a site by scanning it in a “sweep” covering a vertical field of view of 54 degrees and up to 8 freely selectable, 46-degree horizontal fields of view. During each sweep and for each field-of-view, the camera collects one image (i.e., the Kuva GCI360 Camera is image-based, not video-based), similar to the example of Figure 1(c).

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 camera that takes a color image together with each infrared image. Data is processed inside the GCI360 Camera, and processed images are uploaded to the Kuva Cloud Solution, where they are screened to eliminate false positive detections. After this false alarm screening, detection events (if any) are automatically generated by the Kuva cloud solution and the results of the periodic screening are transmitted to the operator as a .gif file for each field-of-view.

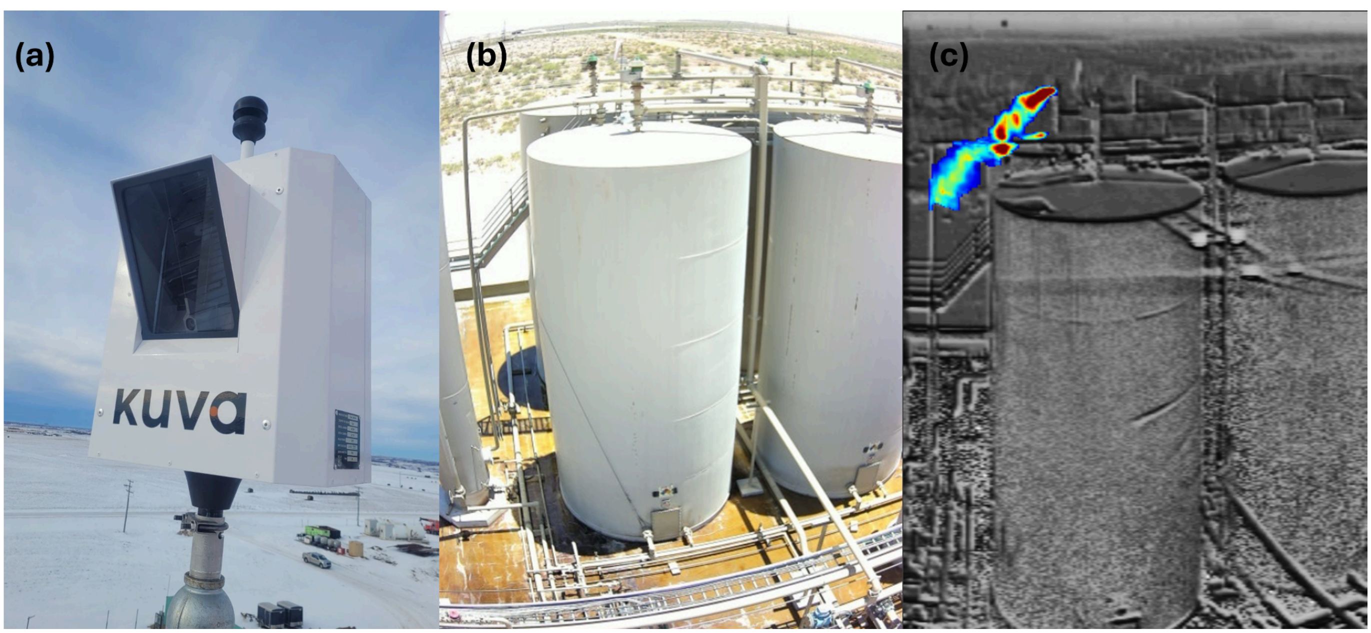

Figure 1: (a) A Kuva GCI360 Camera and mounting pole, (b) RGB color image of tanks being inspected, (c) An example of an image collected when a tank emission occurred.

As a camera based system the Kuva camera is not relying on wind to transport gas to the camera. However, detection sensitivity is dependent on distance. The Kuva system has demonstrated the ability to detect methane emissions at approximately 400 meters distance for larger emission events. The detection performance has been validated in blind testing at Texas Tech University for a distance of 100 meters to the leak source and achieved a 90% probability of detection for sources emitting 14.8 kg of CH_4/h at 100 meters. In this application Kuva is applying for approval as a periodic screening solution capable of a 90% probability of detection at 15 kg of CH_4/h at a distance from the camera of up to 100m. This represents a 200m diameter as the camera rotates 360 degrees around its own axis. The Kuva system also participated in testing at shorter distances 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.[1] Distances to source in this test varied with equipment and were, on average, approximately 20 meters. A re-analysis of the data with an improved algorithm, which was introduced in January 2024, resulted in an equivalent 90% probability of detection of 2.2 kg/h methane for this METEC dataset. Another result of the METEC study is that Kuva provided zero false positive alarms. The Kuva System was found to be the only out of 11 tested point sensor and camera solutions in the METEC test that did not generate false alarms. Kuva's field experience from customer deployments has shown that this significantly increases field acceptance by oil and gas field operations.

The detection performance of the Kuva solution is independent of the temperature of the background or of the gas (delta-T), and it is not affected by the presence of water vapor. Detection performance is affected by the presence of sunlight or cloud cover, distance to the emissions source, precipitation, background reflectivity, and wind speed. The Kuva System can also optionally quantify emissions using a mass-balancing approach. Quantification is based on the path-integrated column density measured at each pixel of the detected gas plume, and it does not rely on inverse dispersion modeling as the emissions are measured at or near their source. Emissions quantification is not part of this periodic screening protocol, and all detected emission events during the screening, irrespective of quantification, are sent to the operator for review.

The Kuva System operates in two modes - periodic screening and custom operating mode. The camera automatically enters periodic screening mode at the start of the 1st calendar day of every month (every other month for sites with bi-monthly screening). In this mode the camera automatically and continuously determines if environmental conditions are within the operational envelope to conduct the periodic screening. Once environmental conditions are favorable, the camera automatically conducts the screening. For the periodic screening images from each field of view are collected, processed in the Kuva GCI360 camera, uploaded to the cloud, and screened for false positives. The results of the periodic screening (irrespective of detections being present) are then automatically sent from the Kuva cloud solution to the operator by API, MQTT or email.

Once the periodic screening has been completed for a given month, the Kuva GCI360 camera enters the custom operating mode. In custom operating mode operators can program the desired camera field of view, quantification and alert criteria as per their specific operational preferences. Examples may include site

[1] Bell, Clay, et. al, Performance of continuous emission monitoring solutions under single-blind controlled testing protocol,https://doi.org/10.1021/acs.est.2c09235, Note: Kuva is solution "J" in the publication (Document ID: SI8)

emissions quantification, monitoring of maintenance activity, monitoring of specific equipment of concern, etc. On the 1st calendar day of the following month (or bi-monthly) the camera automatically returns to the periodic screening mode (overriding the operator specific programming) and the cycle repeats.

In the following sections a more detailed explanation on how the Kuva System works and operational details are provided.

1.2. Description of the physical instrument

The key Kuva system components are illustrated in Figure 2. The components that make up the system are not limited to the figure below and 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 and figure are for reference only. Additional guidance material is included in the Supporting Information file.[2]

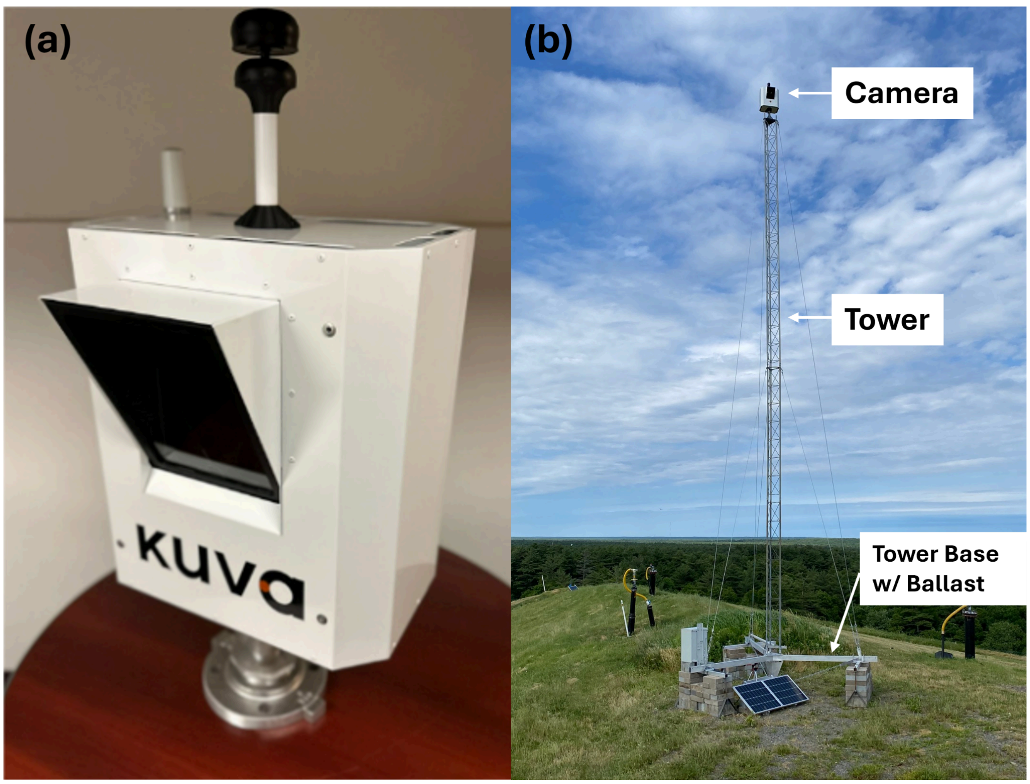

Figure 2: (a) Closeup of the GCI360 camera with integrated ultrasonic anemometer and LTE antenna, (b) A Kuva GCI360 installed atop the optional 40-foot Kuva Tower with ballasted base and guy wires for increased stability.

[2] Kuva Systems user manual. Document included in the Supporting Information file (Document ID: SI2).

- **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. The camera has been successfully tested and operated over multiple seasons in climates from northern Canada to South Texas across -40C to nearly +50C ambient temperatures. The camera is rated IP65 for water and dust resistance.

- **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 power-over-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 a tower for mounting the GCI360 camera, which allows for fast installation without heavy equipment needs.

- **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 transmitted towards the camera via the Power-over-Ethernet cable.

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 straightforward and comparatively 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. Figure 2(a) shows a close-up of the Kuva GCI360 Camera itself, while Figure 2(b) shows an example of a complete Kuva System, including a GCI360 camera, optional Kuva tower, and solar power. On top of the camera, the anemometer and external LTE antenna are visible.

1.3. Scientific theory

The fundamental principles of operation of the Kuva System are passive remote sensing and imaging spectroscopy in the shortwave infrared (SWIR) portion of the electromagnetic spectrum. The GCI360 camera performs both of these functions using single-pixel detection techniques and X-Y scan control for image formation. Unlike conventional Optical Gas Imaging, which relies on gas detection via thermal infrared emissions in the mid-wave or long-wave spectrum, the Kuva GCI360 Camera does not rely on detecting thermal emissions, and therefore does not rely on temperature differences for gas detection.

Remote sensing in the SWIR can be performed either actively (using a SWIR light source such as a laser projected out from the sensing device) or passively, using an external SWIR light source such as the sun. The Kuva System employs a passive remote sensing approach to detect methane emissions at facilities using reflected sunlight in the 2.0 - 2.5um wavelength range. Passive imaging in the SWIR regime is widely used for methane monitoring in aerial applications (e.g., Insight-M) as well as by satellites (e.g., MethaneSAT, GHGSat, Sentinel, TROPOMI). The Kuva System detects methane and hydrocarbon emissions around the 2.3um band. A description of related techniques for atmospheric methane retrievals from a scanning SWIR imaging instrument can be found in Varon et al. (2021) who produced methane plumes from Bands 11 and 12 of the Sentinel-2 multispectral imaging satellites.[3]

Figure 3 shows the schematic of the measurement system. SWIR light is emitted by the sun and reflected and scattered by the background. Common backgrounds include groundcover, equipment, structures, buildings, and vegetation; no mirror or specialized reflectors are required. If sunlight traverses a plume of methane or other hydrocarbons - either between the background reflection point and the GCI360 camera or between the sun and the background reflection point - it gets partially absorbed. The amount of absorption is proportional to the amount of gas present that is traversed by a solar ray, allowing for a path-integrated measurement computed as column density value expressed in ppm-m units. By scanning the single pixel in the x- and y-direction, every pixel represents a path-integrated column density measurement, thereby allowing the visualization of the gas plume in a color gradient.

[3] Varon, D. J. *et al.* High-frequency monitoring of anomalous methane point sources with multispectral Sentinel-2 satellite observations. *Atmos. Meas. Tech.* **14**, 2771–2785 (2021).

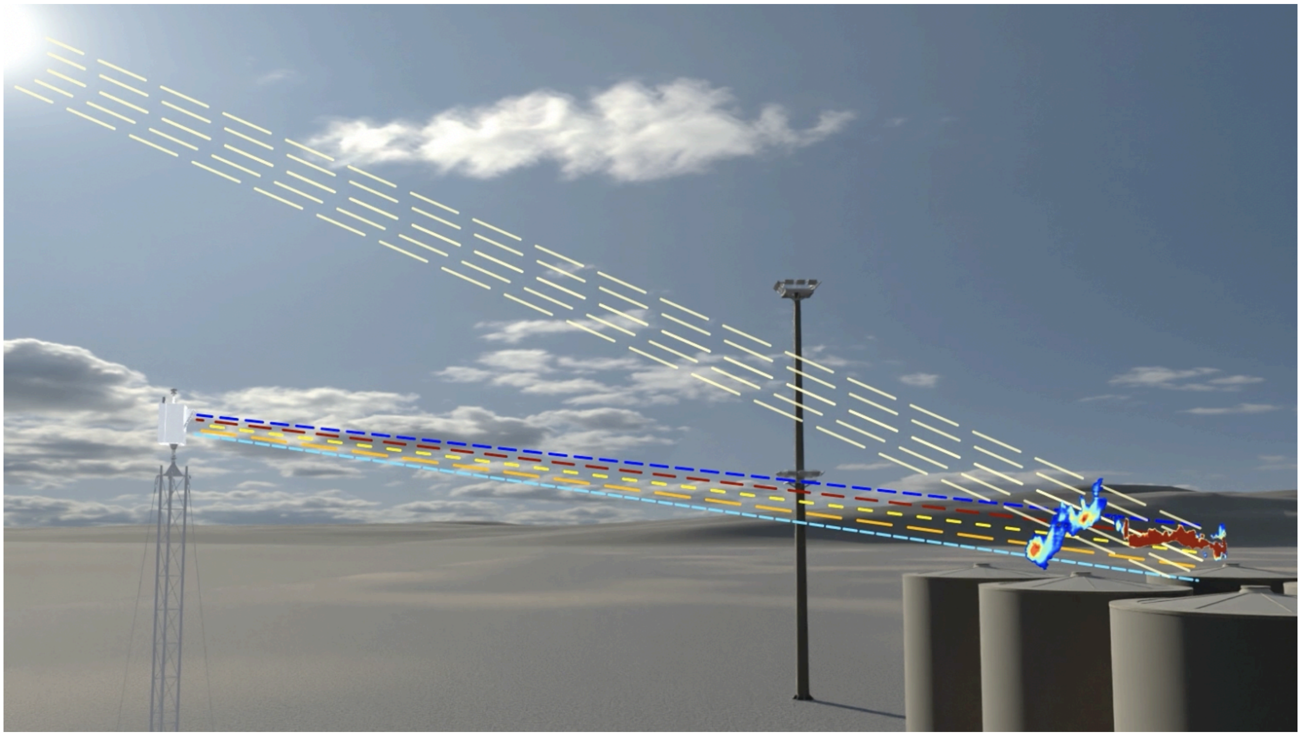

Figure 3: A representation of an imaging geometry where solar radiation passes through gas and then reflects off one or more surfaces in the scene towards the Kuva GCI360 Camera, which detects the gas absorption. Solar radiation, in other cases, may reflect off ground surfaces first, then be absorbed by gas before reaching the camera.

In imaging spectroscopy, each pixel of an image contains multiple spectral bands of information, each of which can be used to identify features of interest based on the unique spectral properties of gasses of interest. The spectral resolution of the instrument is used to classify it as either multispectral (fewer spectral bands) or hyperspectral (hundreds of bands). The Kuva GCI360 Camera is a multispectral instrument based on intellectual property developed by MultiSensor Scientific, Inc.[4] Detection is based on multiple photosensors with multiple 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 GCI360 Camera does not require an integrated gas cell.

In order to generate an 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 4. The horizontal scan speed is approx. 2° per second. The scan speed for a 46-degree field-of-view is approximately 26 seconds.

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[4] Waxman, A. M., Bylsma, J. M., & Vaitses, A. (2019). *Scanning IR sensor for gas safety and emissions monitoring* (United States Patent US10436710B2).

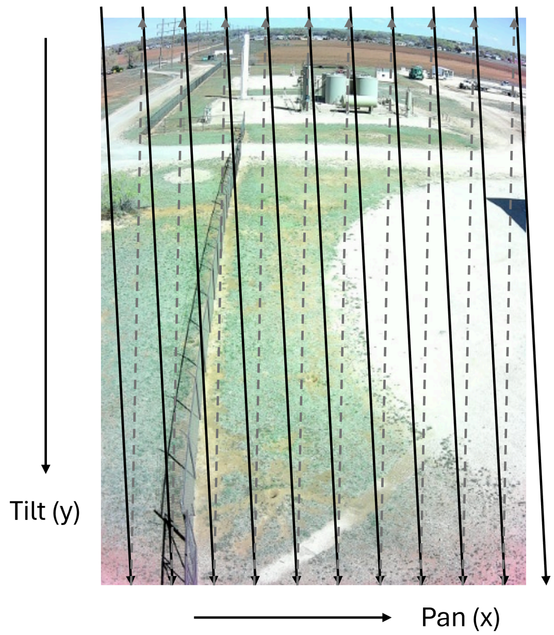


Figure 4: Raster scan pattern employed by the Kuva GCI360 Camera. Full field of view is 46° (H) x 54° (V)

The collected pixel-by-pixel infrared data is represented in a rectangular image format representing 46 x 54 degrees and subsequently processed 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.

A quantification of the plume image can optionally be conducted using the well-known mass balancing approach to calculate the hydrocarbon mass emission rate. The mass balance approach aims to determine the mass emissions rate by calculating the mass of gas passing through a surface per unit area per unit time. Emissions quantification is an optional function and is not part of this work practice for periodic screening. Instead, under this work practice emission events are created based on detected emissions and irrespective of their quantification.

1.4. Type of measurement, desired application, availability for use

The type of measurement with the Kuva system is a method. As a camera based system it is classified as a “stationary remote sensor”. The desired applicability is “Broadly applicable across the sector”. The solution has been developed by Kuva Systems internally, Kuva Systems is located in the United States and the solution is “readily available for use” as it has been repeatedly sold or leased to the general public (including upstream and midstream oil and gas operators). Limitations of the technology are discussed in chapter 3.4.

2. Operation of the Kuva system

2.1. Calibration, installation, commissioning and maintenance

2.1.1. Calibration

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 monitoring 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.

2.1.2. Installation, Commissioning and Maintenance

The installation and commissioning workflow is summarized in Figure 5 below and described below.

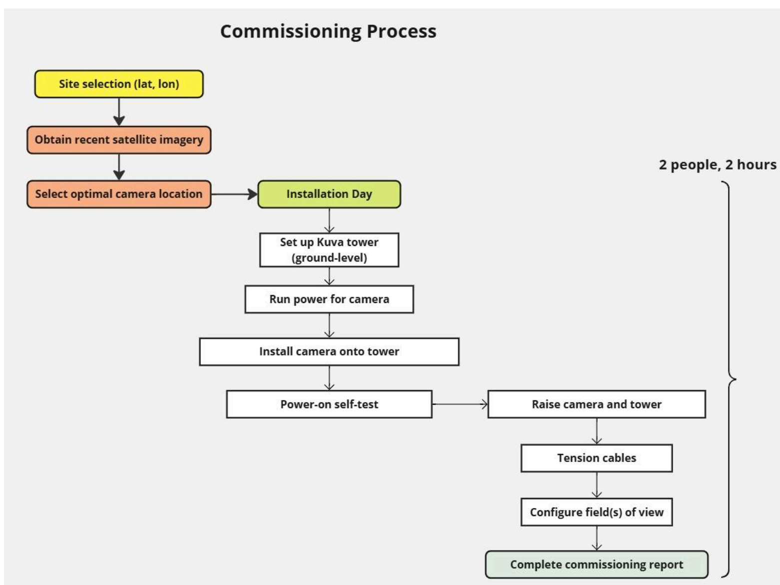


Figure 5: Example workflow for site selection, camera placement, installation, and commissioning of a GCI360 camera and utilising the optional Kuva tower. The workflow is equivalent for other poles, towers or mounting structures used and for other methods of obtaining site data.

Prior to the deployment of a Kuva System, a site evaluation based on overhead imagery, a site plan or equivalent data is conducted to determine the location of the Kuva System to be installed. For a potential camera position on the site, each potential leak source is within 100m range of the camera pole / tower base and within the 54 degrees vertical field-of-view. 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 tower / pole base to the farthest equipment to be monitored is validated to be at or below 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 System 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.

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 by the installer 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 relevant equipment. Additionally, GPS coordinates of the camera, timezone, and scanning schedule are set up during this procedure. For sites such as compressor stations with equipment subject to LDAR requirements located inside enclosed buildings, coverage 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. An example of a commissioning report is shown in Figure 6 below. An example of an overhead view with camera placement, fields-of-view and distances is shown in Figure 7 below.

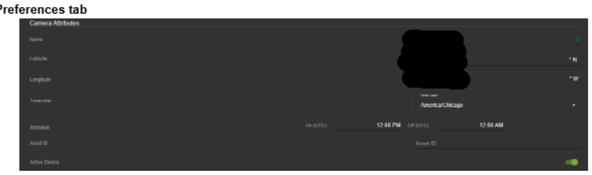
kuva Commissioning Report

Telemetry data

Device				
Timestamp	2023-11-07T17:41:17.9541767Z			
Metric	**Measured Value**	**Min Value**	**Max Value**	**Pass/Fail**
Average Voltage (V)	22.4	22	30	Pass
Average Current (Amps)	1.1	0	1.75	Pass
RSSI (If on cell)	-55.0	-80	0	Pass
Average Ping Speed (ms)	55.0	N/A	N/A	Pass
Humidity (%)	14.7	0	95	Pass
Wind Speed (m/s)	4.9	N/A	N/A	Pass
Wind Direction (degrees)	89.0	0	360	Pass
Sensor TEC (C)	-20.0	-19.995	-20.005	Pass

KuvaOS Version	**3.2.10**
CameraApp Version	**4.10.47**

Preferences tab



Panoramic view

Figure 6: Example Commissioning Report verifying camera connectivity, image uploads, metadata, and field-of-view configuration before installers leave the site.

Figure 7: Example of overhead imagery of a facility, Kuva System placement, multiple fields-of-view of the camera and distance measurements.

The GCI360 Camera is designed for 40,000 total hours of maintenance-free operation. In rare cases malfunctions have been observed in field installations, in most cases due to loss of power or data connectivity. 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. To ensure data quality, the Kuva cloud solution monitors the performance characteristics and health of the GCI360 Cameras and generates alarms in case of malfunctions. The InGaAs sensor technology and related solid-state 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). 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.

2.2. Data collection

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 (see Figure 4 above). The field-of-view segments are fixed to 46 degree horizontal each but can be freely chosen in their rotational position up to 360 degrees of coverage (i.e. 8 fields of view). They can be adjacent to each other, partially overlapping or separated (see also Figure 9 above). 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 approximately 26 seconds per 46-degree field of view.

The Kuva System operates in two modes - periodic screening and custom operating mode. The camera automatically enters periodic screening mode at the start of the 1st calendar day of every month (every other month for sites subject to bi-monthly screening at 15 kg/h). In this mode the camera automatically and continuously determines if environmental conditions are within the operational envelope to conduct the periodic screening. This is achieved by the camera calculating and monitoring a 5-frame average detection capability score for each field of view. The score represents a value that reflects the impact of light signal received by the camera, noise detected by the camera, and local wind speed and direction on the ability to detect low levels of emissions. When a capability score of a pre-set limit is met for an average of 5 images, the Kuva System processes these images as a periodic screening. This process continues until all fields-of-view that were programmed during camera commissioning have recorded a valid periodic screening. The detection capability score limit to enter periodic screening was determined based on the distribution of capability scores that were observed during the blind testing that determined the probability of detection at 100m distance (see section 3.2).

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 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 or via API), informing the operator to plan for a substitute OGI inspection for the given month for the site the camera is located at.

Once the periodic screening has been completed for a given month, the Kuva GCI360 camera enters the custom operating mode. In custom operating mode operators can program the desired camera field of view, quantification and alert criteria as per their specific operational preferences. Examples may include site emissions quantification, monitoring of maintenance activity, monitoring of specific equipment of concern, etc. On the 1st calendar day of the following month the camera automatically returns to the periodic screening mode (overriding the operator specific programming) and the cycle repeats.

2.3. Data processing

Data processing is conducted in multiple phases which are described in the three sections below:

1. Detection capability score calculation
2. Gas detection
3. False alarm screening in the cloud

2.3.1. Data processing for capability score calculation

An overview on data processing during periodic screening mode is provided in the chapter above on data collection.

2.3.2. Data processing for gas detection

Pixel-by-pixel raw infrared data collected by the Kuva GCI360 Camera is processed automatically inside the camera to generate an infrared image for a given field-of-view. Moreover, for every infrared image collected, one visible RGB image is taken as well and processed into a compressed image file.

Algorithms running inside the camera convert raw infrared data (signal levels received by a processor from each multispectral photodetector) into a ppm-value for every pixel. Every pixel in every infrared image represents a ppm-m (column density) reading of hydrocarbon gas. Column density is the same unit measured by plane or satellite based imaging systems, by open path detectors or by scanning laser tower systems. Additional algorithms processing the entire infrared image determine gas may be present in which case the image is marked as a “detection candidate”. 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 every field-of-view all 5 collected infrared images and associated RGB images are uploaded to the cloud, irrespective if gas is detected or not.

For an image to be created, the gas does not have to be blown to the GCI360 Camera, as the camera is a standoff detection solution. Moreover, Kuva does not rely on dispersion modeling or correlation with other atmospheric data sources to infer emission sources. Instead, the gas column density measurement across a given field of view directly creates the image that provides evidence of the emission as well as localization to its source.

2.3.3. Data processing for false alarm screening in the Kuva cloud during periodic screening mode

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 alarms. If a single image is 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 5 greyscale infrared images (including plume overlay, if any) and one consisting of the 5 RGB images collected. The GIF file contains 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.

2.4. Data documentation and reporting

2.4.1. Processed data documentation

Data records are processed and temporarily stored in the camera or in the secure Kuva cloud solution. These databases and other resources have the security, controls, and compliance in accordance with System and Organization Controls Type 2 (SOC 2) certification. SOC 2 certification attests that system security, availability, and processing integrity meet the needs of industrial applications.

Data related to a monthly periodic screening is maintained at a minimum until the successful transmission of the GIF files to document the monthly screening to the operator. Data retention and record keeping requirements for the transmitted data reside with the operator as per applicable OOOOb/c regulations. Kuva is frequently also contracted by the operator to also retain data beyond the time of data transmission to the operator.

2.4.2. Data reporting and data retention

Data transmission of all GIF files from the Kuva cloud solution to the operator happens automatically as soon as the false alarm screening and file generation has concluded. In accordance with the monthly periodic screening frequency, the GIF files documenting the results of the periodic screening are transmitted once per month to the operator - independent if gas has been detected or not. The file transmission serves as evidence for the operator to document that the periodic screening has been conducted by the Kuva solution and to record the date and time of the periodic screening. Transmission of GIF files is conducted via an application programming interface (API), by MQTT or as an attachment to an email that is generated by the cloud solution and addressed to the responsible operator email address registered for the site. Upon transmission of the files for the monthly screening to the operator all data retention and record keeping requirements remain with the operator. Optionally, the data can also be retained and viewed in the Kuva cloud solution by the operator if the operator contracts for it.

3. Technical system performance

3.1. Spatial resolution

Third-party blind testing at Colorado State's METEC facility showed that the Kuva System can localize emissions to the component level in 99% of all test cases.[5] Since data is collected in image form, users of the Kuva GCI360 Camera can, in almost all cases, pinpoint emissions to their source component based on visual review of the image data. However, as 100% pinpointing to the component level cannot be guaranteed, this application is for a spatial resolution at the "area level".

3.2. Probability of Detection in blinded controlled release testing

The Kuva System is a periodic screening solution with a 90% probability of detection (PoD) of 14.8 kg CH_4 / hr at 100m distance and 90% PoD of 2.2 kg/h at 20 m distance. Importantly, both values were obtained in conjunction without any false positive detections. The PoD was established through blind testing at METEC and at Texas Tech University.

3.2.1. Colorado State University - METEC Blind Test Program (April 2021 - October 2021)

Kuva participated in METEC's single-blinded controlled release program under the ADED protocol over a 5-month period in 2021. The test program uses METEC's test facility featuring a full-scale tank battery in a dry gas setup, 10m x 10m well pads, a compressor station, and more to support emissions detection and quantification technologies, as well as methods development and training.

The procedure Kuva followed while participating in the blind test program was to regularly submit detection reports, indicating the start and stop time of detected emissions as well as the detected emission source, as well as reports indicating when the Kuva System was not collecting data (i.e., nighttime) so that releases conducted during offline periods would not be counted. Overall, a total of 787 controlled releases were performed within these bounds at rates from 0.135 to 146 SLPM whole gas. The primary aim of the test program was to develop a probability of detection (PoD) curve for each participating technology. Kuva's PoD curve from METEC testing is presented in Figure 8 and has been published.[6]

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[5] Bell, Clay, et. al, Performance of continuous emission monitoring solutions under single-blind controlled testing protocol, https://doi.org/10.26434/chemrxiv-2022-4hc7q-v3, Ref: Table 2, solution "J" in the publication.
[6] Bell, C., Ilonze, C., Duggan, A., & Zimmerle, D. (2023). Performance of Continuous Emission Monitoring Solutions under a Single-Blind Controlled Testing Protocol. *Environmental Science & Technology*, *57*(14), 5794–5805. https://doi.org/10.1021/acs.est.2c09235, Kuva is solution J

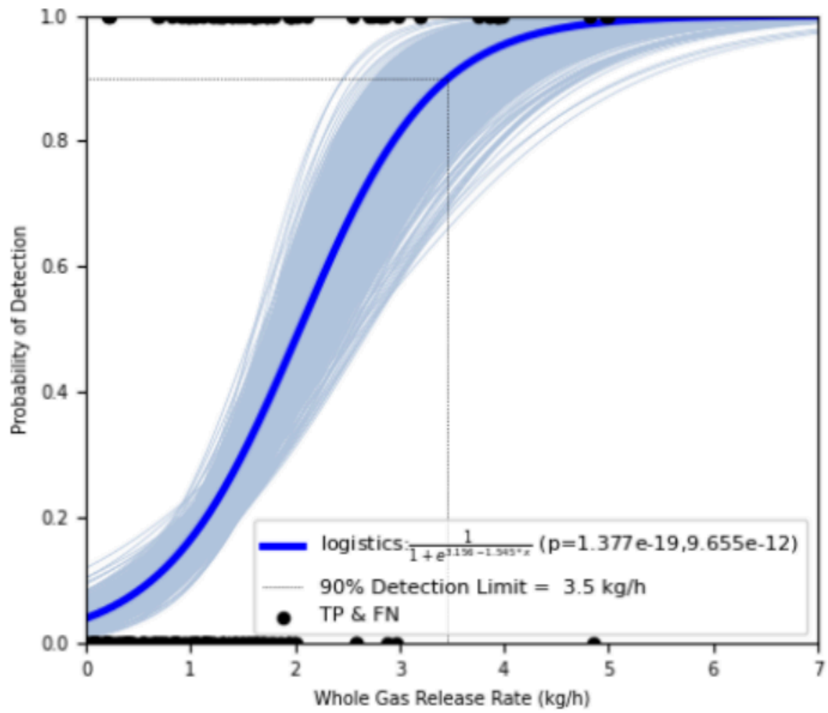

Figure 8: Kuva Probability of Detection (PoD) curve at METEC in 2021, published in Bell et. al., Kuva is solution J

This curve shows a 90% probability of detection for an emissions rate of 3.5 kg/h (81.7 SLPM or 173 SCFH). The Kuva System demonstrated a 50% PoD at 2.0 kg/h and a 10% PoD around 0.8 kg/h. Furthermore, the Kuva System demonstrated zero false positive alarms reported over the duration of the test program. Data was collected over a five-month period under a variety of weather conditions during the day. The resulting probability of detection curve is therefore representative of a mix of weather and cloud conditions in Colorado and takes the above listed limitations into account for daytime operation. Night-releases were disregarded by the METEC team when calculating the probability of detection.

A subsequent improvement to the detection algorithm and a re-analysis of the METEC data with the 2nd generation detection algorithm resulted in an updated 90% probability-of-detection of 2.2 kg/h.

3.2.2. Texas Tech University - Oilfield Technology Center (Spring 2024)

Similar to METEC, the Oilfield Technology Center at Texas Tech University (TTU) features non-operational upstream equipment, including a 2x2 battery of 20-foot tanks, a heater treater, and other equipment. The equipment was donated by operators in the Permian Basin to Texas Tech for educational purposes, and it provided a relevant setup for conducting controlled gas releases. Texas Tech personnel has set up controlled gas releases with a commercial mass flow controller, gas cylinders, and tubing that allows for multiple emission sources to be placed in a scene to a distance of up to 180 m and emission rates from 10 SCFH (0.2 kg/h) up to ~1200 SCFH (25 kg/h).

In Spring 2024 TTU conducted a controlled release test of the Kuva solution to establish the probability of detection at 100m distance in a blind test. The test was conducted with the updated algorithm mentioned in section 3.2.1 above. The results provided by TTU demonstrate a probability of detection of 91% at 100m.[7] Kuva utilized the blind test data set to determine the limit for the detection capability score that is described under section 2.2.

3.2.3. Stanford University Blind Test Program (October 2022 - November 2022)

During the Fall of 2022, Kuva participated in a blind test campaign conducted by Stanford University along with other point sensors, cameras, aerial sensors, and satellites. The aim of the testing was to evaluate the performance of multiple methane measurement technologies in addressing the problem of large emissions from unlit flares. Emissions were conducted from an elevated location. One Kuva System was installed at the test location. Kuva submitted detection reports, wind telemetry, and “offline reports" just as with ADED testing under the METEC Blind Test Program described above.

The test releases conducted in October and November 2022 spanned from 0.037 kg/h to over 2,800 kg/h methane mass flow rates. The Kuva detection rate, or True Positive Rate for event-based reporting, was published as 91.9%.[8] A probability of detection curve can not be determined from this data set due to limitations in the data collected and in the definition of what is considered a true positive.

3.3. Performance in field deployments

3.3.1. Emissions Reduction Alberta (November 2020 - June 2024)

Under an ERA-funded demonstration project, Kuva has installed systems for long-term use at 16 upstream sites owned by 3 companies for at least one complete year each. All systems were in Alberta, Canada, and have been in continuous operation through all seasons. Three of these systems are installed at a gas plant owned and operated by Whitecap Resources and are part of their Alberta Energy Regulator-approved Alternative Fugitive Emissions Management Program. These installations are representative of how the systems will be deployed.

Results of the demonstration project are that the camera successfully operated at sustained temperatures below freezing, including temperatures as low as -38 degrees Celsius. Due to the downward slanted window of the camera, snowfall slides off the camera and does not stick to the window. In rare cases ice would freeze against the window, however it melted within hours due to the internal heat generation of the camera (approximately 25 Watt). The camera successfully and regularly detects emissions against snow covered backgrounds. Shorter days in the winter reduce the number of hours suitable for detection, however even in the middle of the Alberta winter every month had dozens of hours of a suitable operating window.

3.3.2. Commercial deployments (July 2021 - Present)

Kuva started commercial sales and deployments of the Kuva System in July 2021. Since then a triple digit number of Kuva systems has been installed at sites from dozens of operators in the US and Canada, and several systems installed internationally.

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[7] See supporting document SI1 for the letter from Texas Tech University certifying the results

[8] Chen, Z., El Abbadi, S. H., Sherwin, E. D., Burdeau, P. M., Rutherford, J. S., Chen, Y., Zhang, Z., & Brandt, A. R. (2024). Comparing Continuous Methane Monitoring Technologies for High-Volume Emissions: A Single-Blind Controlled Release Study. *ACS ES&T Air*, acsestair.4c00015. https://doi.org/10.1021/acsestair.4c00015

Cameras have been successfully deployed across basins including Permian, Eagle Ford, Anadarko, Denver-Julesburg, Bakken, Marcellus and Green River representing a representative range of environmental conditions for the continental United States.

Commercial deployments in the Bakken have confirmed excellent performance under cold and winter conditions. Deployments in the Permian Basin have demonstrated very good resilience to blowing sand and dust, as these particulates have difficulty sticking to the downwards sloping window of the camera, as with snow.

3.4. Method limitations

3.4.1. Weather related limitations

The system does not detect emissions under the following conditions:

- Lack of sufficient SWIR illumination received by the camera (at night, heavy precipitation, thick cloud cover, low reflectivity of background, shadows)
- Very high wind speeds

The camera regularly operates in diffuse light, in partially cloudy conditions, with a wide variety of ground cover (reflectivity varies by type of ground) and with snow cover. The camera performs well on snow-covered surfaces in freezing conditions as long as there is not a significant amount of standing water on top of the snow (i.e. melted snow) as standing water absorbs infrared light.

Although the Kuva GCI360 camera regularly detects larger emission events in wind speeds greater than 10 m/s, the probability of detection decreases with increasing wind speed as gas plumes are much more rapidly dispersed by the wind.

In order to account for these limitations Kuva is utilizing a detection capability score that is calculated for every image taken to reflect the then prevailing environmental conditions. The detection limit for any environmental conditions depends directly on the signal-to-noise of SWIR light received at the camera detector as well as the speed of dispersion of a plume due to the wind. Therefore, the detection capability score is based on the infrared light received at the sensor, the noise level at the sensor as well as prevailing wind conditions. Periodic screening is only conducted if the detection capability score is above a preset limit that reflects the condition under which the controlled release testing was conducted. See chapter 2.2 for more details.

3.4.2. 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 pass through the plume of methane and reflect off background scattering surfaces. 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.

3.4.3. False Positive Detections

All infrared gas cameras produce a certain number of false alarms which are related to the camera's underlying physical principle. The Kuva GCI360 Camera takes direct measurements of gas absorption tuned to hydrocarbons in the shortwave infrared. By operating in the shortwave infrared band, the GCI360 Camera does not rely on temperature differences but instead detects reflected sunlight. However, it does occasionally create false detections based on thin objects made out of hydrocarbons (e.g., plastics and polymers) as well as certain types of glare spots, as these tend to reflect sunlight in a way that appears similar to hydrocarbon absorption. To minimize false positives, all detection candidates are screened in the Kuva cloud solution. See section 2.3.3 for more details on the false positive screening.

3.4.4. Application Limitations

As the Kuva camera cannot detect emissions located inside buildings, there is an application limitation for compressor stations with equipment subject to LDAR requirements located inside compressor buildings. Any equipment located inside such buildings to be inspected with OGI or EPA Method 21 at the applicable inspection frequency for the 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 System placement. The camera is designed for onshore use and not recommended for use in offshore applications.