Advancing Livestock Emissions Measurement: ZELP Sense

1. Introduction

Methane (CH_4) is a potent greenhouse gas (GHG) with a global warming potential approximately 28 times greater than carbon dioxide (CO_2) over a 100-year period (IPCC, 2021). One of the largest anthropogenic sources of CH_4 emissions is enteric fermentation in ruminants. As part of their digestive process, ruminants rely on microbial fermentation within the rumen to break down fibrous plant material. This fermentation process produces CH_4 as a byproduct, which is expelled primarily through eructation. Livestock-related CH_4 emissions contribute significantly to climate change, representing approximately 30% of global anthropogenic CH_4 emissions (Gerber et al., 2013).

Addressing CH_4 emissions from cattle is crucial for mitigating climate change. Unlike CO_2, CH_4 has a relatively short atmospheric lifetime of about 12 years (Mar et al. 2022), meaning that reducing emissions can have a near-immediate impact on slowing global warming. Additionally, CH_4 reduction strategies in cattle have the potential to improve feed efficiency, as less energy is lost in the form of gas emissions (Løvendahl et al., 2018). However, accurately measuring and monitoring CH_4 emissions from cattle remains a significant challenge due to variability in individual animal metabolism, diet, and environmental conditions.

Limitations of Existing Methane Measurement Methods

Respiration chambers are considered the gold standard for measuring CH_4 emissions from cattle, by collecting and analyzing exhaled breath. However, they are expensive and do not provide readings in a real-world setting. Like other existing continuous measurement techniques for individual animals, such as SF6 Tracers, they also require high labour input and animal training. Alternative short-term measurement techniques, such as GreenFeed [a feeder spot sampler] and sniffers contain additional variations in timing and frequency of measurements obtained relative to the 24 hour feeding cycle, making them less accurate [though more scaleable]. (Yiguang et al., 2020).

Method	Cost	Advantages	Disadvantages
Respiration and accumulation chambers	Generally high	Highly accurate, controlled environment; information about individual animals	Results different from free-range animals; configurations still vary from one research group to another; an animal adaptation period is required; every 2–3 h accumulation chambers must release CO_2 that builds up
Hood and/or head box systems	Moderate to high	Portable and less expensive than a chamber; requires less space	Do not measure hindgut emissions; an animal adaptation period is required; not designed for grazing situations but are used in those conditions frequently
Tracers	Moderate	Accurate; few interferences by other gases; the animal can free range	Rely on SF_6, which is a greenhouse gas itself; does not completely capture all tracer and, therefore, relies on spot concentration measurements; high contact with animal, whihc can disrupt normal behavior
Gas sensor capsules	Low	Compatible with new electronic technologies; relies on small, low-cost sensors; continuous measurements	Information about relation between concentration and flux (emission); still under development
In vitro measurements	Low	High reproducibility but used to rank feeds for methaogenic potential and not for measurements of flux; allows different rumen microbial environments to be evaluated	Outcomes can be different from actual measurements; method relies on donor animals for rumen environment; standardization can be difficult
Field measurements	High	Information about many animals; data produced in natural grazing environment	Require expensive and accurate measurement approaches: data processing heavily influenced by microclimatic conditions; loss of data can be high
CH_4 emission models	Low	Estimate the distribution of production; not limited to any configuration	Can be different from real scenatios; still rely on input data made from respiration and accumulation chambers measurements as

Figure 1. Table describing the various CH_4 measurement methods (Hill et al., 2015)

A New Approach: ZELP Sense

ZELP, a UK-based ag-tech company, aims to revolutionize livestock emissions monitoring by developing Sense, a low-cost, easy-to-use, wearable device that provides real-time, non-invasive emissions measurement for individual cows.

Unlike existing techniques, Sense allows continuous tracking of CH_4 and CO_2 emissions in natural settings, enabling accurate, behaviourally relevant and scalable data collection. It has potential to support the agricultural sector's transition to more sustainable and climate-friendly practices, whilst protecting productivity and efficacy.

This report describes the Sense system, its development process, and key findings from chamber validation work and in-house tests used to refine ZELP's measurement technology.

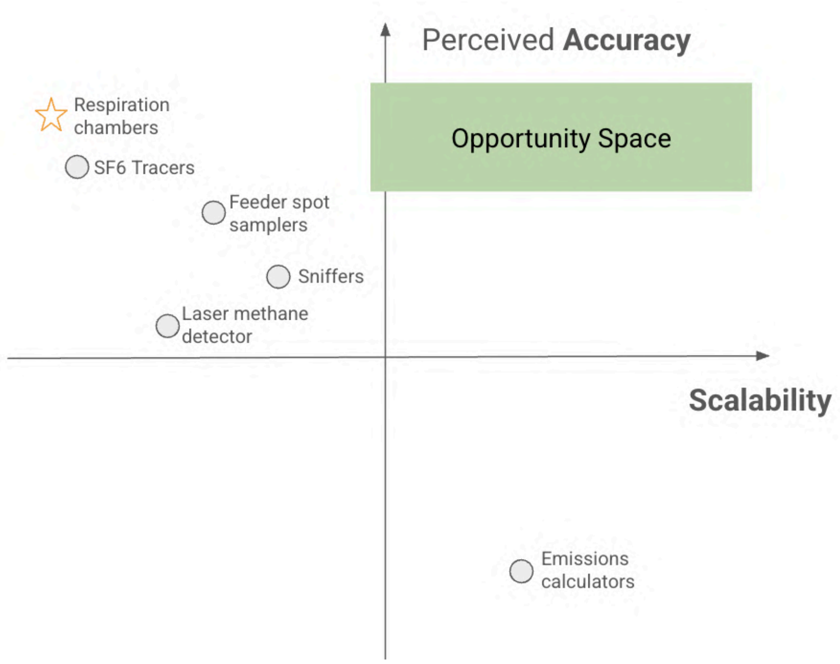

Figure 2. Diagrammatic representation of current methods used for measuring methane and areas where there is opportunity for improvement.

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2. System Description

ZELP Sense has undergone multiple design iterations to enhance accuracy, durability, and comfort for cattle. The system regularly samples the cow's breath, analyzing gas levels to calculate total emissions. The key components include:

Headgear, Nosepiece & Gas Sensing Area

Engineered for a secure fit with minimal discomfort, ensuring effective gas capture. The headgear serves as the base for all other components, helping position the nosepiece, which routes samples of eructated and ambient gas to sensors in the gas sensing area. The optimal placement of this area is still under evaluation, with one possibility being around the cow's neck.

Figure 3. Full depiction of the Sense device and the usages of each component.

Sensors & Functionality

- CH_4 and CO_2 sensors measure gas concentrations in the cow's breath.
- Flow sensors track air movement through the device.
- Environmental sensors monitor temperature, humidity, and pressure.

Pipeline Processing & Delivery via App

Emissions related data from the wearable device is processed by ZELP's Machine Learning models. Insights are then delivered in an easy-to-view format on ZELP's mobile-optimised web app.

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3. System Development

Bessie (Breathing and Eructation Simulator):

To help develop and refine ZELP Sense, ZELP developed Bessie (Figure 4), a breathing and eructation simulator. It has been used to enhance sensor accuracy, and enable rigorous in-house testing before field deployment, helping ensure that ZELP's emission monitoring system performs optimally in real-world conditions.

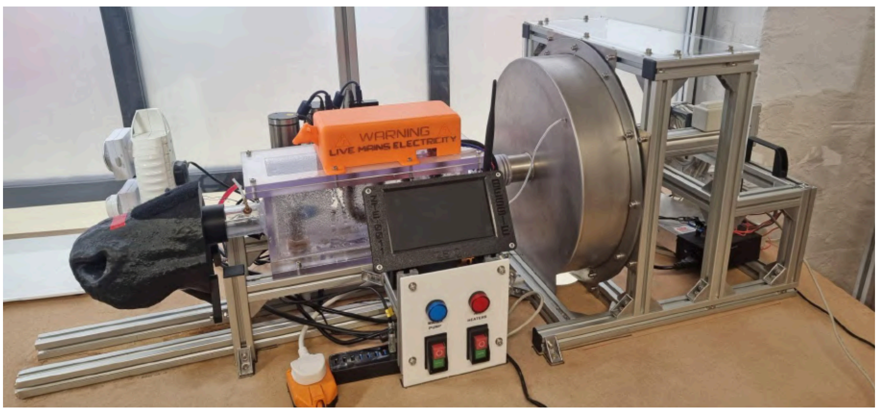

Figure 4. Full set-up of Bessie.

Key Functions

- Simulates cow breathing with adjustable breath patterns, including realistic tidal volumes, as well as inhalation and exhalation rates.
- Replicates eructations with precise gas mixtures, at desired ratios of CH_4 and CO_2.
- Controls breath temperature to match realistic conditions.
- Incorporates a humidification system to ensure properly humidified breath.

Notable Data

- Achieves consistent and reliable breath patterns, helping improve device validation.
- Produced 100% humidity readings, helping successfully validate humidity sensors.

Abrasion Testing for Optimal Animal Wearability

Ensuring animal comfort and welfare is a key priority in wearable livestock monitoring. Poorly designed headgear can cause skin abrasions, hair loss, and discomfort, impacting overall welfare.

To ensure Sense's materials and design are optimized for long-term cattle wearability and effectiveness, ZELP used a Linear Abrasion Tester Machine (Figure 5). This machine allows a cow hide sample to be secured to the platform whilst the material sample is secured at the base of the vertical steel arm (circled in yellow). Once test parameters are set to detail the number of strokes and weight on the sample, the test is run with the vertical arm running horizontally along the hide. Hair loss and bald spot calculations are completed once the test has finished.

Figure 5. Linear Abrasion Tester Machine

Methodology

Samples (15x40 mm) were tested against genuine cowhide under controlled weight and stroke conditions:

- **Weights:** 0g, 250g, and 500g
- **Duration:** Equivalent of 1 month of animal wear.

Results

- Hair loss and abrasion were closely linked to material properties, weight, and surface texture, emphasizing the importance of material selection.
- Heat-shrunk polyethylene (PE) with foam exhibited the highest hair loss, indicating the most abrasiveness.

- Polyethylene terephthalate glycol (PETG) and upholstery leather resulted in less hair loss.
- Breathable neoprene, after the equivalent of a month of use on animals (Figure 6), led to no visible hair loss pattern.

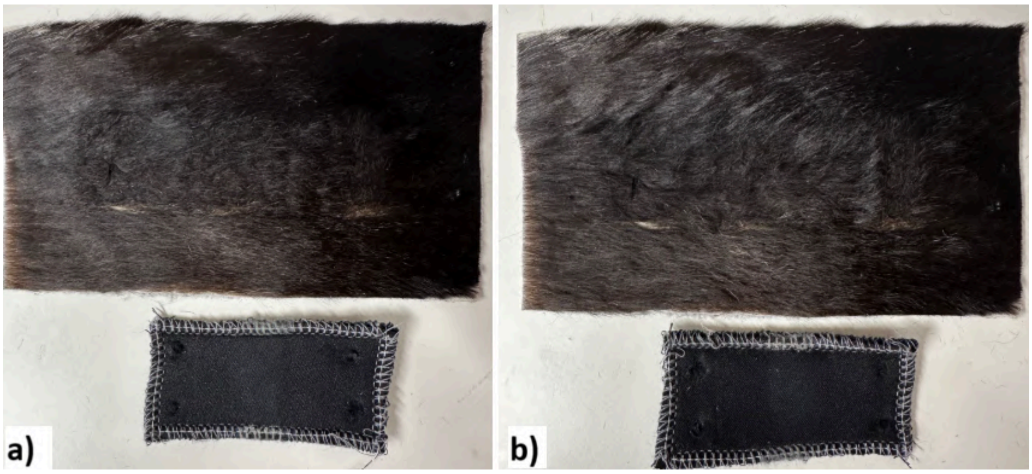

Figure 6. Breathable neoprene before (a) and after (b) a test simulating 1-month of wear on an animal.

Additional Benefits of Breathable Neoprene

Breathable neoprene not only eliminates hair loss but also allows for greater airflow, reducing heat buildup and preventing excessive sweating — additional factors in ensuring long-term wearability and welfare. Ongoing testing continues to validate its performance.

Conclusion

Material choice plays a crucial role in wearable livestock device design. Initial linear abrasion testing identified breathable neoprene as a suitable choice, with subsequent real-world testing confirming its use aligns with best practices for animal comfort and overall welfare.

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4. Chamber Trial Validation

To validate the accuracy of Sense, ZELP conducted controlled chamber testing. This involved placing cows in a respiration chamber, where environmental conditions and gas exchange were precisely monitored. The objectives were to assess the accuracy of Sense in comparison to respiration chambers, collect high-resolution gas emission data, and ensure Sense did not negatively impact animal welfare.

Methodology

Three cows, fitted with the Sense device, were tested in respiration chambers over a 3-week period, with two separate 3-day testing sessions conducted, separated by a one-week break.

Sense continuously captured CH_4 and CO_2 concentrations. Data transmission was conducted via onboard storage and wireless connectivity.

The sensor readings from ZELP Sense were then compared against the chamber's reference values, allowing ZELP to assess measurement accuracy and reliability against the gold standard method.

Key Findings

- Sense demonstrated moderate to strong positive correlations with respiration chamber readings, suggesting reliable CH_4 and CO_2 measurements.
- Sense achieved an RMSE of ≦20%, indicating a relatively accurate prediction with an average error of <20% relative to chamber values.
- Respiration rates remained within the normal range of 26–50 breaths per minute, with no observed distress or behavioural changes.
- Weight loss was consistent with expected patterns in respiration chambers, where feeding is restricted.

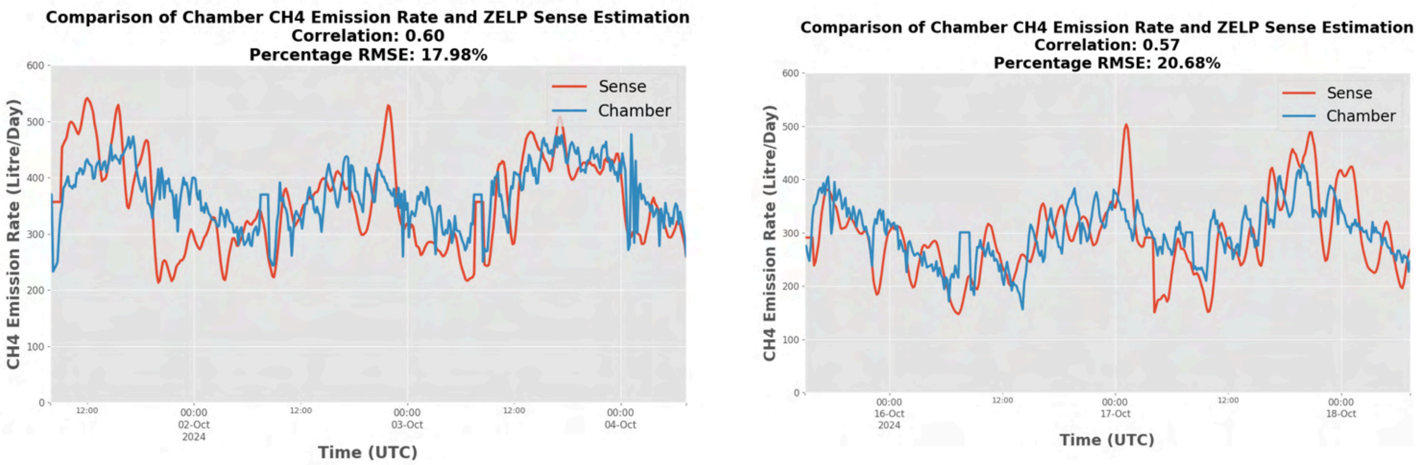

Figure 7. CH_4 graphs comparing the Sense readings to the chamber readings over the trial period.

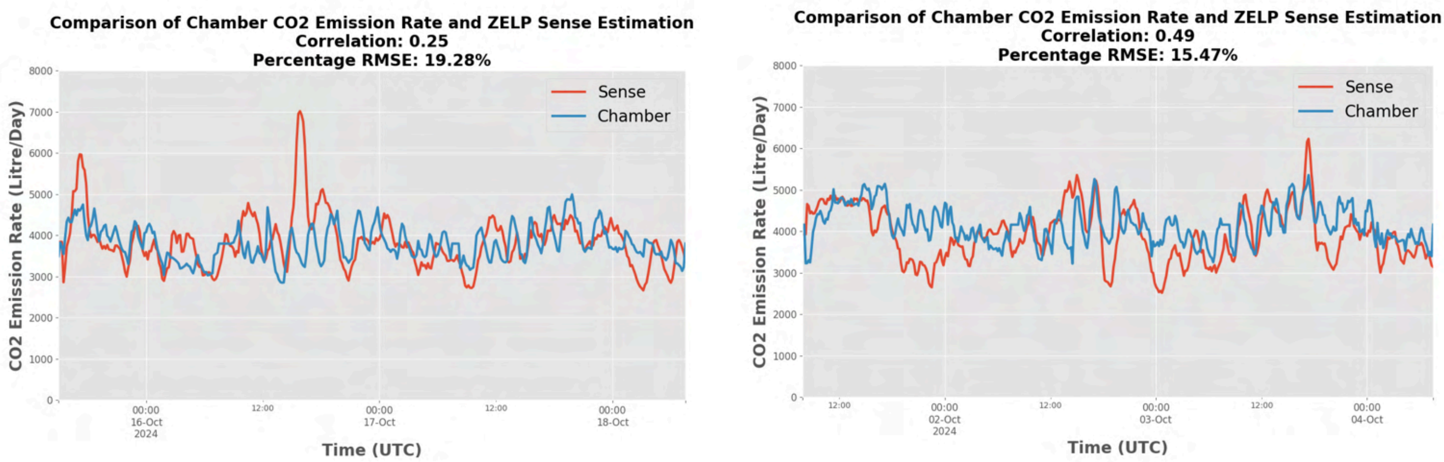

Figure 8. CO_2 graphs comparing the Sense readings to the chamber readings over the trial period.

5. Conclusion & Next Steps

ZELP Sense offers reliable and accurate, real-time CH_4 and CO_2 emissions monitoring for individual cows. Rigorous abrasion testing and monitored chamber and barn deployments have shown it causes no negative impact on animal behavior or welfare. Combined with its low-cost and ease of scalable manufacturing, ZELP Sense looks set to be a more affordable, widely-deployable, and user-friendly alternative to existing measurement solutions.

Future research will include further barn and grazing deployments, and additional benchmarking versus existing measurement techniques, conducted both internally and with external organizations. Commercial release is currently planned for H2 2026.

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