DIGITAL LIVESTOCK LAB

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

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# Leveraging artificial intelligence to optimize farm management decisions

## Artificial Intelligence in Agriculture

https://dorealab.cals.wisc.edu


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Department of Animal and Dairy Sciences
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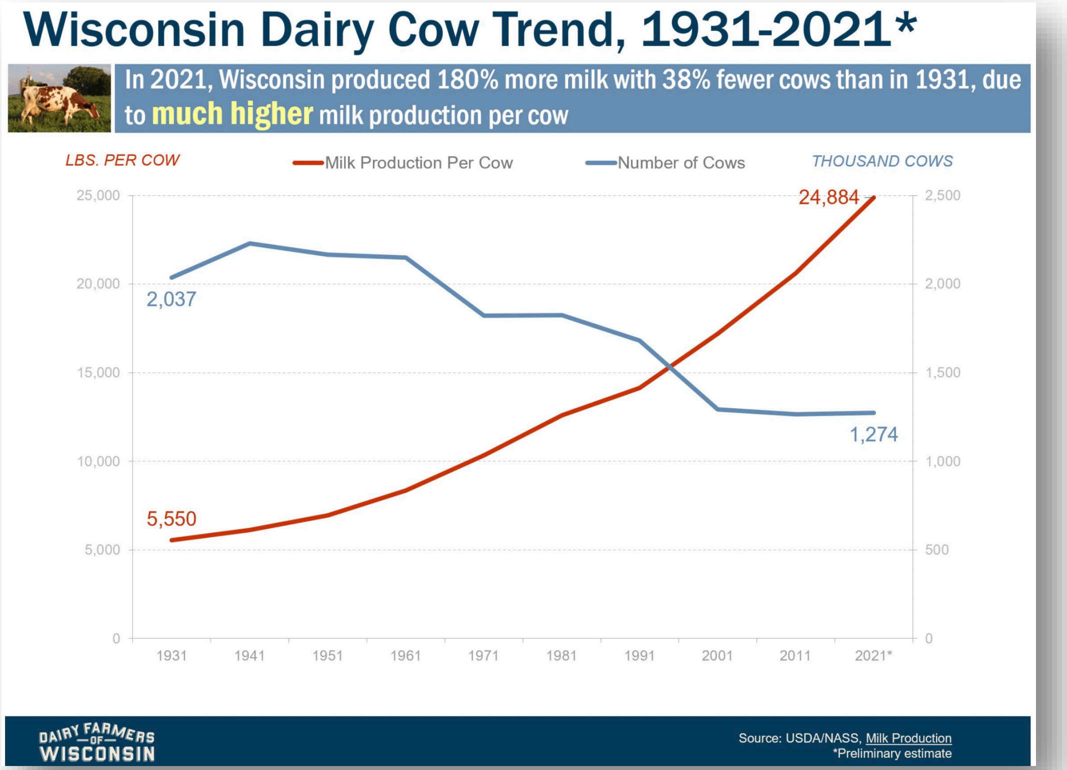
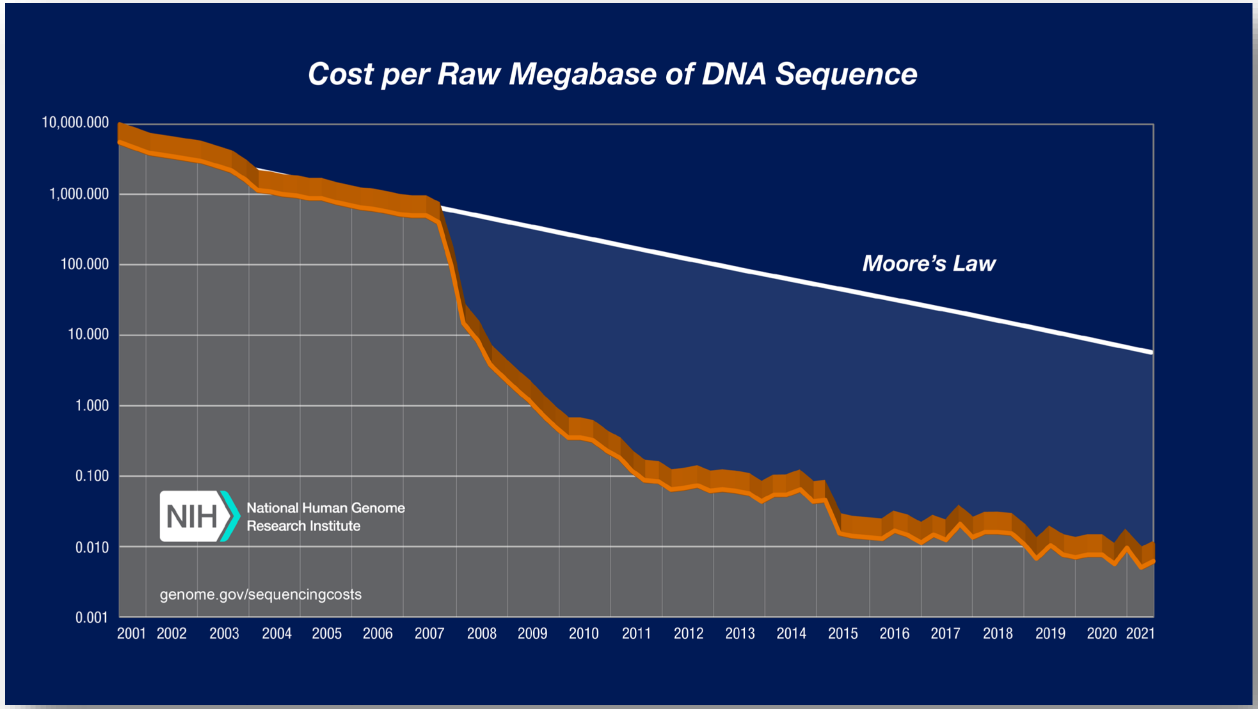
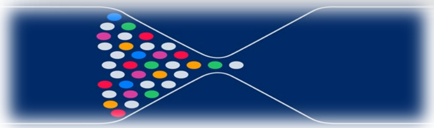
# Genomics: Amazing Progress!




Costs to genotype drastically decreased over time!



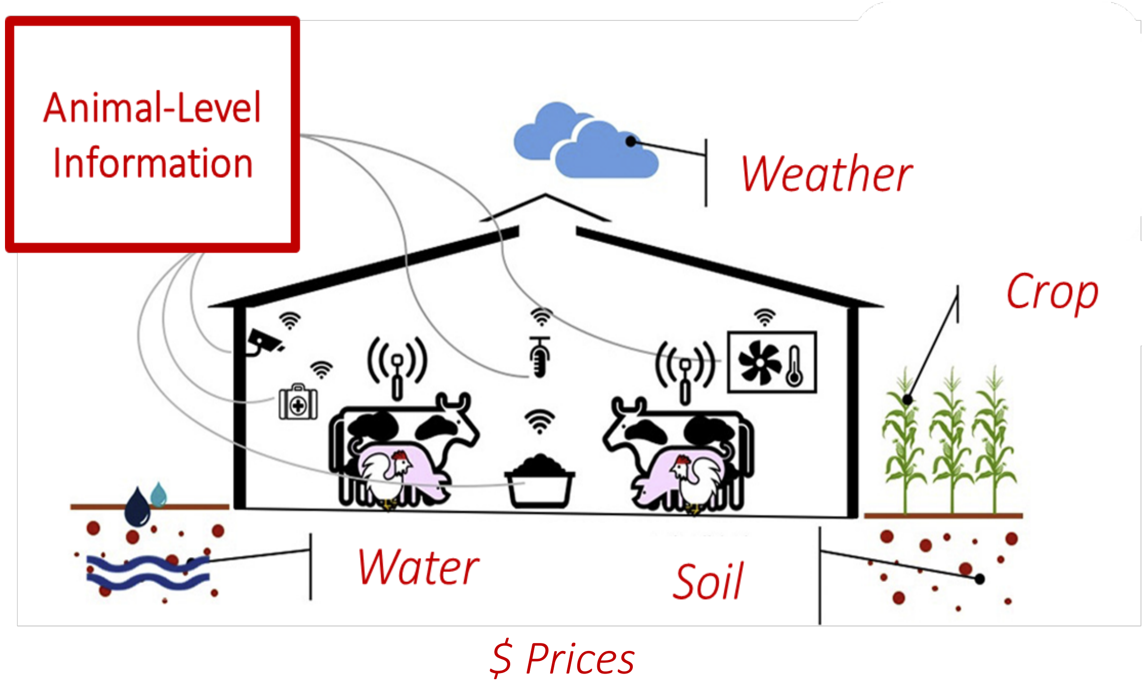

Genomics, Transcriptomics, Proteomics, Metabolomics, Epigenomics, Microbiomics, etc.



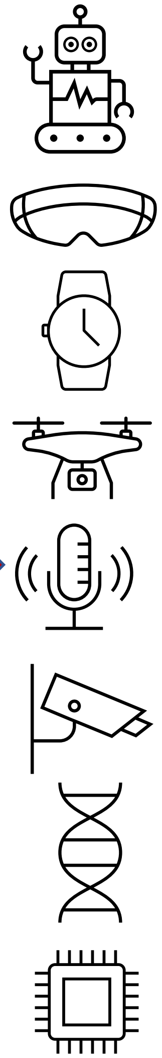
High-Throughput Phenotyping
"Phenomics"

# Sensing Technologies: Individual Animal

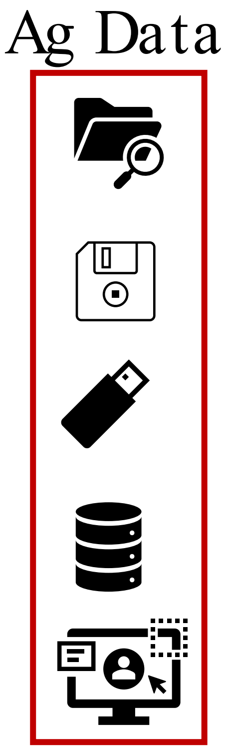
- For large-scale phenotyping:
  "sensing technology is the solution"

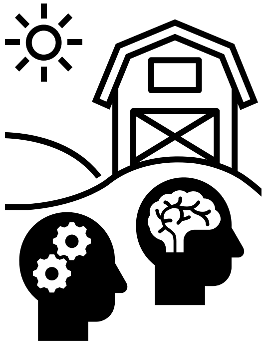



## Multi-Sensor Systems



Animal Behavior
Traceability
Infectious Disease
Body Composition
Methane Emission
Social Interaction

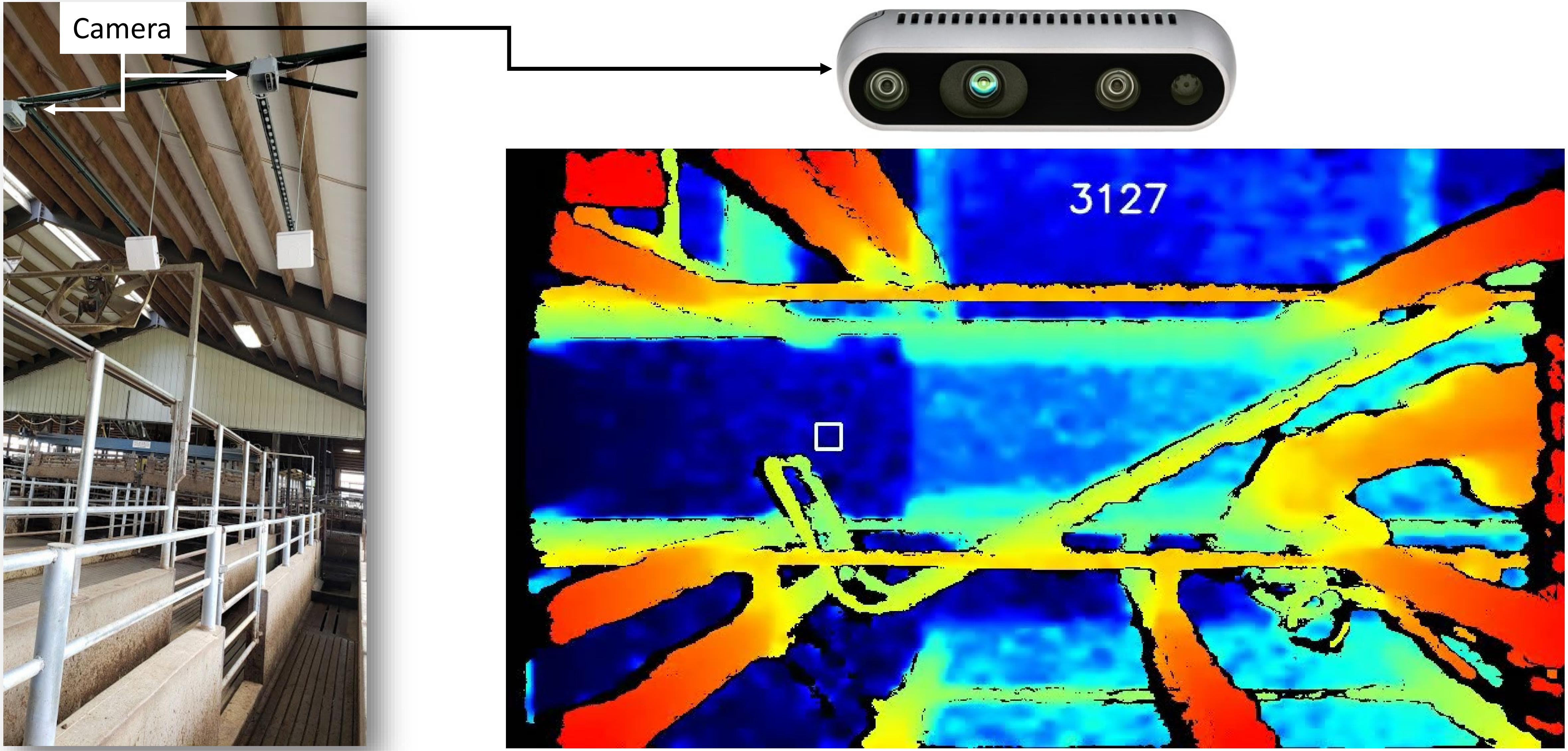


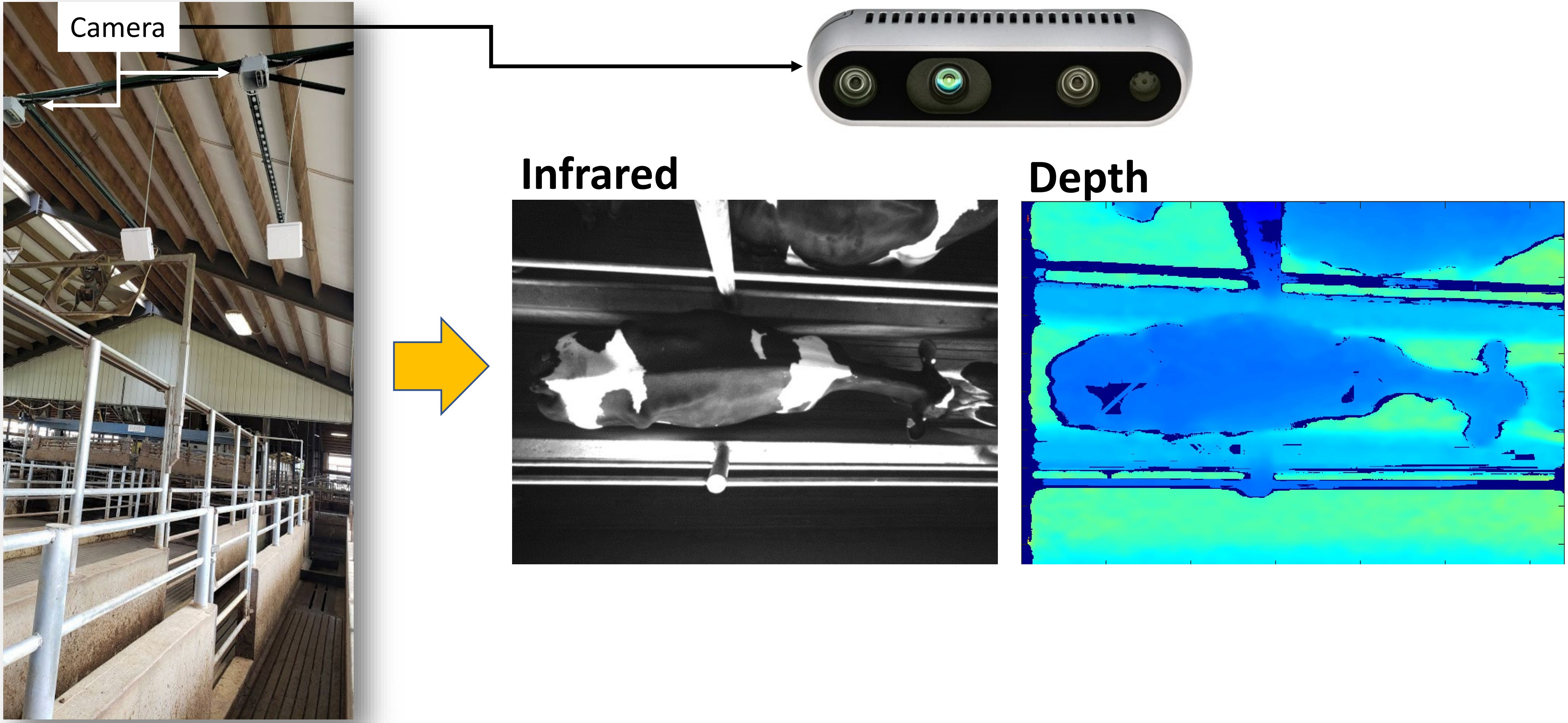
**On-farm management Decisions (short-term $)**

**Genetic Selection (long-term $)**

# Implementing AI in Livestock Operations



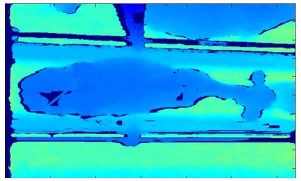
# Implementing AI in Livestock Operations



# Automation: Cloud-Computing Framework

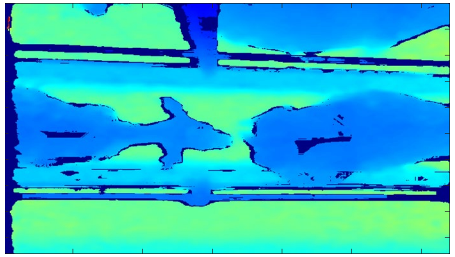

**Infrared**

**Depth**

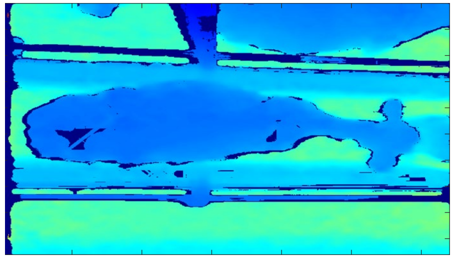


## *1st Step: Image Classification*

**Bad**



**Good**

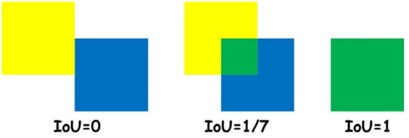


*Xception (Chollet, 2017)*
*2D CNN*
*Accuracy = 97%*
*52,247 total → 19,592 selected*

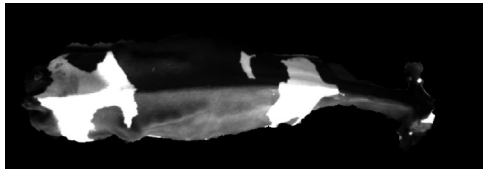
*If good:*

## *2nd Step: Image Segmentation (Mask)*

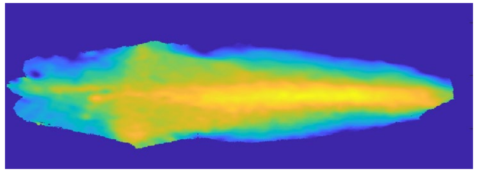
*U-Net (*Ronneberger et al., 2015*)*
*2D CNN*
*Intersection Over Union = 0.93*




## *3rd Step: Image Identification (Animal Identification)*

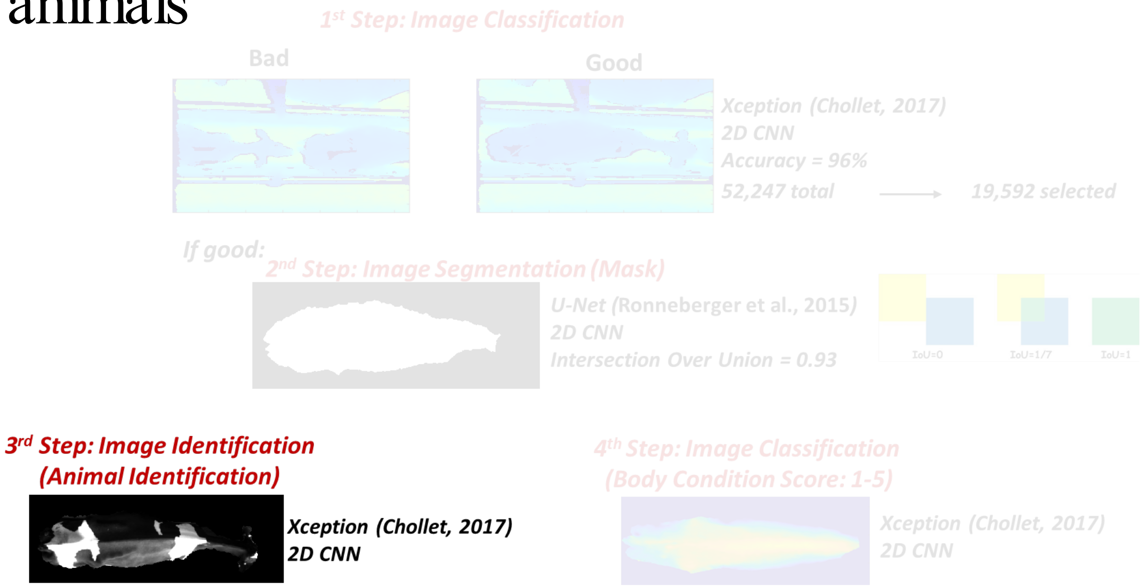


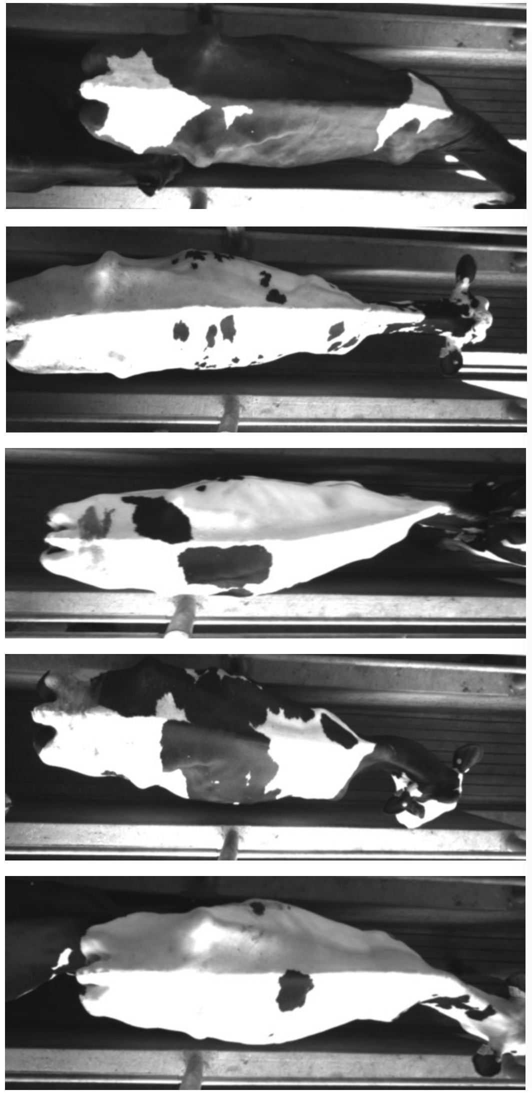
## *4th Step: Image Classification (Body Condition Score: 1-5)*



# Animal identification using 2D images

- 92 lactating dairy cows;
- Training set: 16,055 images automatically acquired at UW-Madison;
- Testing set: 3,680 images test
- Deep Learning (CNN; Xception)
- Mean Accuracy: 96% to identify individual animals




Ferreira et al., 2023 – Scientific Reports

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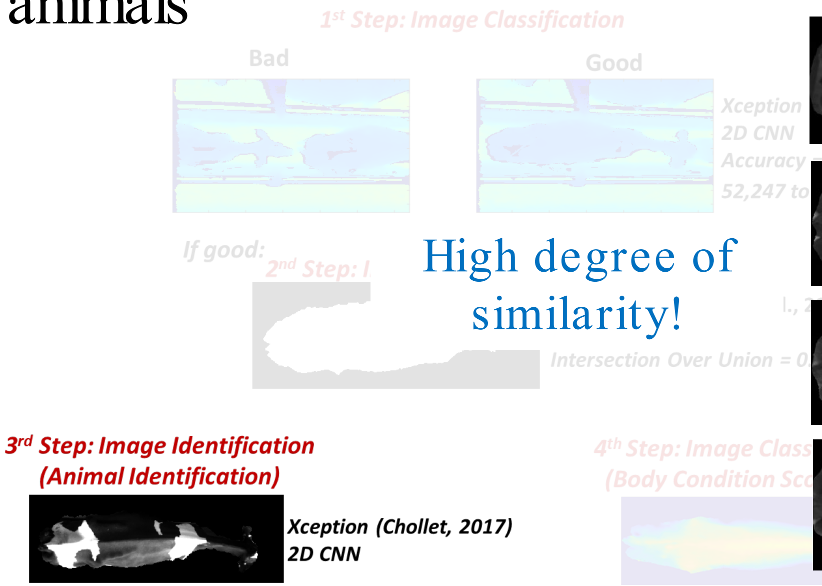
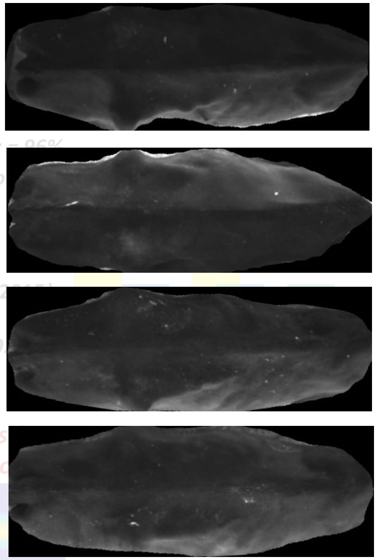
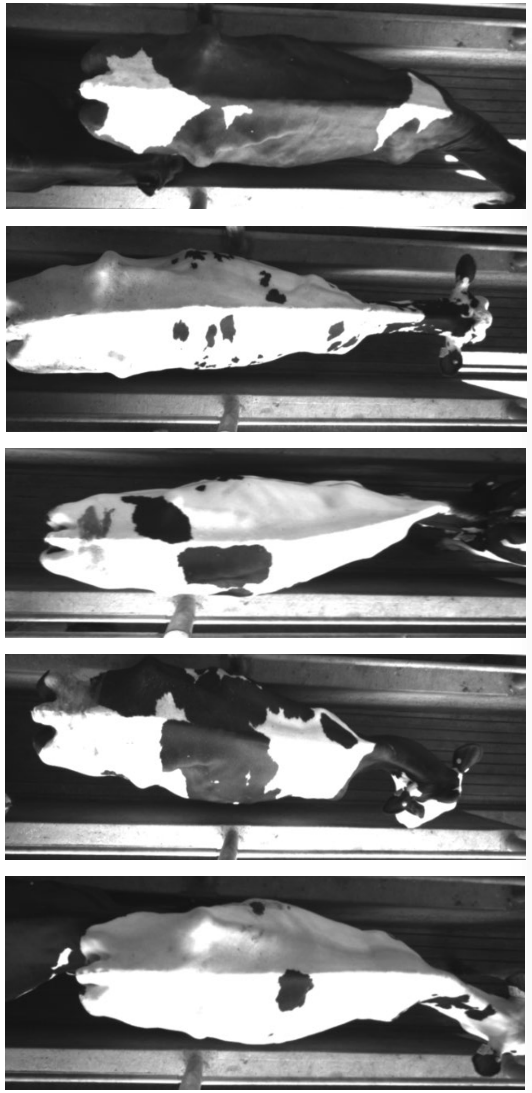


High degree of similarity!

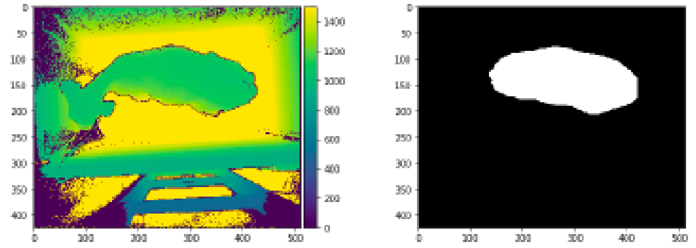



Ferreira et al., 2023 – Scientific Reports

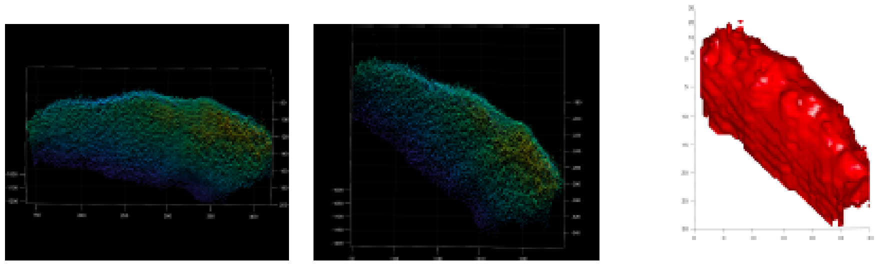
# Animal Identification: 3D representation

3D images:
Voxels (VoxNet; Maturana and Scherer, 2015)
Point cloud (PointNet; Qi et al., 2016)

2D images:
Depth images
(VGG16, Xception, Inception v3)



(a) Original depth frame (b) Output from Mask R-CNN



(c) Generated point cloud (d) Augmented point cloud (e) Generated occupancy grid

RO = *Random*
CO = *Chronological*

| Train-test split | Data representation | Architecture | $F_1$ score |
|---|---|---|---|
| RO[1] | DI[3] | VGG16 | 0.888 |
| RO[1] | DI[3] | Inception v3 | 0.904 |
| **RO[1]** | **DI[3]** | **Xception** | **0.959** |
| RO[1] | PC[4] | PointNet | 0.669 |
| RO[1] | OG[5] | VoxNet | 0.880 |
| CO[2] | DI[3] | VGG16 | 0.718 |
| CO[2] | DI[3] | Inception v3 | 0.750 |
| **CO[2]** | **DI[3]** | **Xception** | **0.804** |
| CO[2] | PC[4] | PointNet | 0.429 |
| CO[2] | OG[5] | VoxNet | 0.656 |

How frequent should I retrain the algorithms?

F1-score

| Time interval | Xception | PointNet | VoxNet |
|---|---|---|---|
| No skipping | **0.917** | 0.533 | 0.917 |
| 1 week | **0.846** | 0.551 | 0.831 |
| 2 weeks | **0.835** | 0.441 | 0.806 |
| 3 weeks | **0.856** | 0.282 | 0.792 |

*Ferreira et al., 2022 – Computer and Electronics in Agriculture*

# Animal Identification: Keypoints

## Animal Identification

- Keypoint model (Newell et al., 2016)
- 4,319 top-down view images
- SNN animal identification
- 11,499 top-down view images
- 41 dairy cows, 5 different days;

## BW and HH prediction

- 1,592 top-down view images
- 87 beef-on-dairy, 5 months

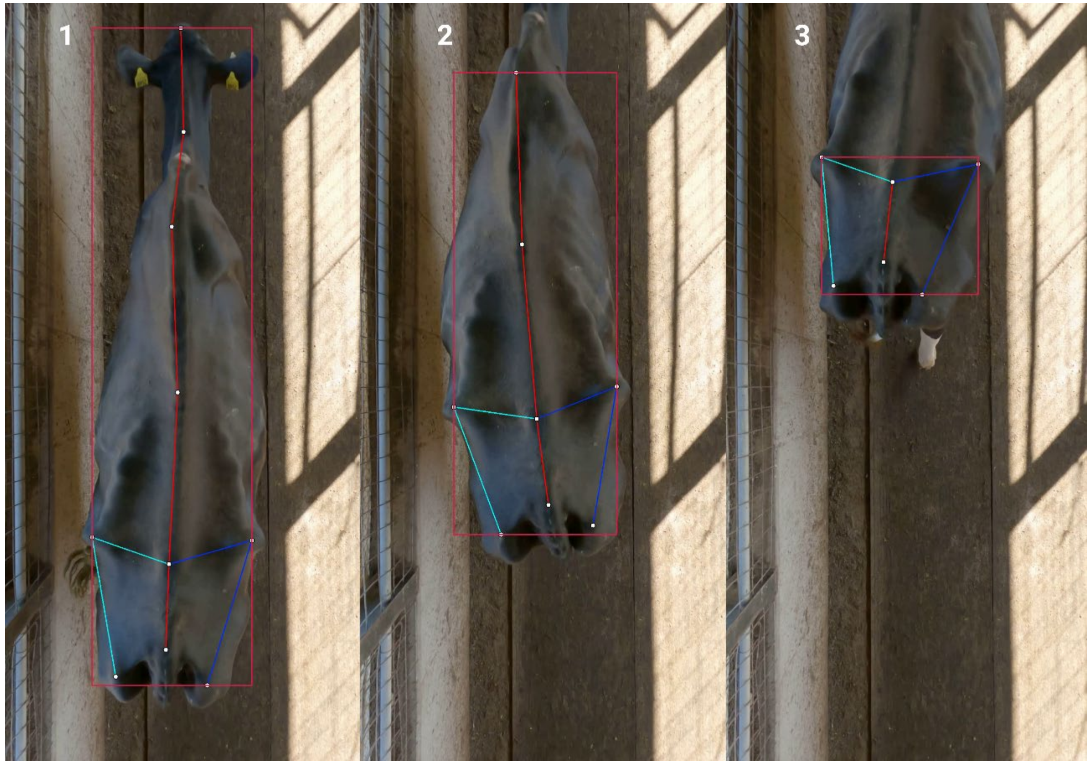


Figure 1: Predicted keypoints strategy 1, 2 and 3. The images were generated using the testing set

# Animal Identification: Keypoints

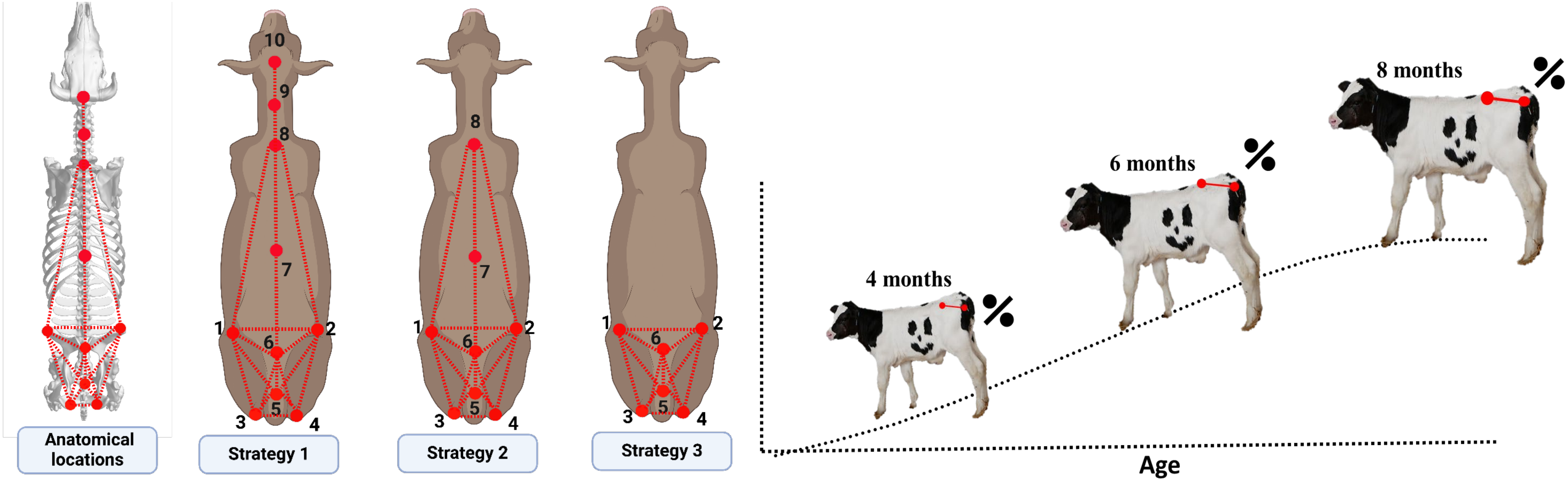



Figure 2: Description of measurement sites for Euclidean distance as a Feature

F1, F2, F3, F4, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18 and F19 represents the Euclidean distance between the following points + all nineteen distances standardized as percentage of the sum of all distances, respectively: 1→2; 3→4; 5→6; 1→3; 2→4; 3→6; 4→6; 3→5; 4→5; 1→6; 2→6; 1→5; 2→5; 6→7; 7→8; 1→8; 2→8; 8→9; 9→10

# Model performance on closed set

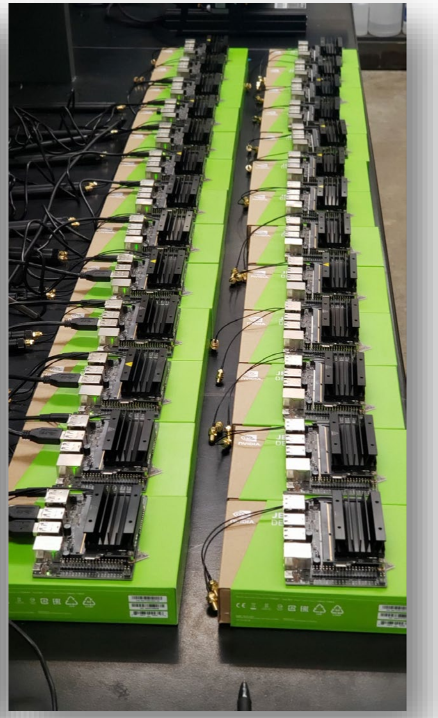
Accuracy, precision, F1 scores, and recall calculated at the frame level and using mode prediction to identify individual cows in closed-set scenarios

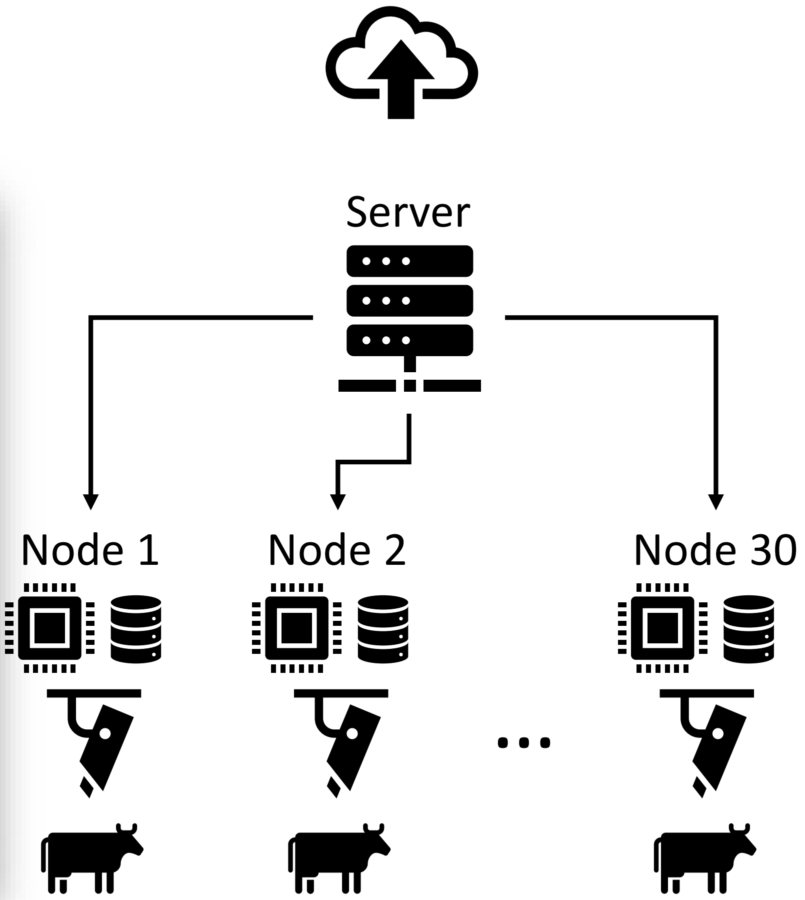
| SNNs | | Test | | | |
|---|---|---|---|---|---|
| Method | N° | Accuracy | Precision | F1 - Score | Recall |
| Keypoint Prediction majority vote | | | | | |
| Strategy 1 | 188 | 96.3 | 96.3 | 95.9 | 96.0 |
| Strategy 2 | 188 | 93.1 | 93.4 | 92.5 | 92.6 |
| Strategy 3 | 188 | 81.9 | 84.2 | 80.9 | 81.6 |

# Artificial Intelligence: Sensor System

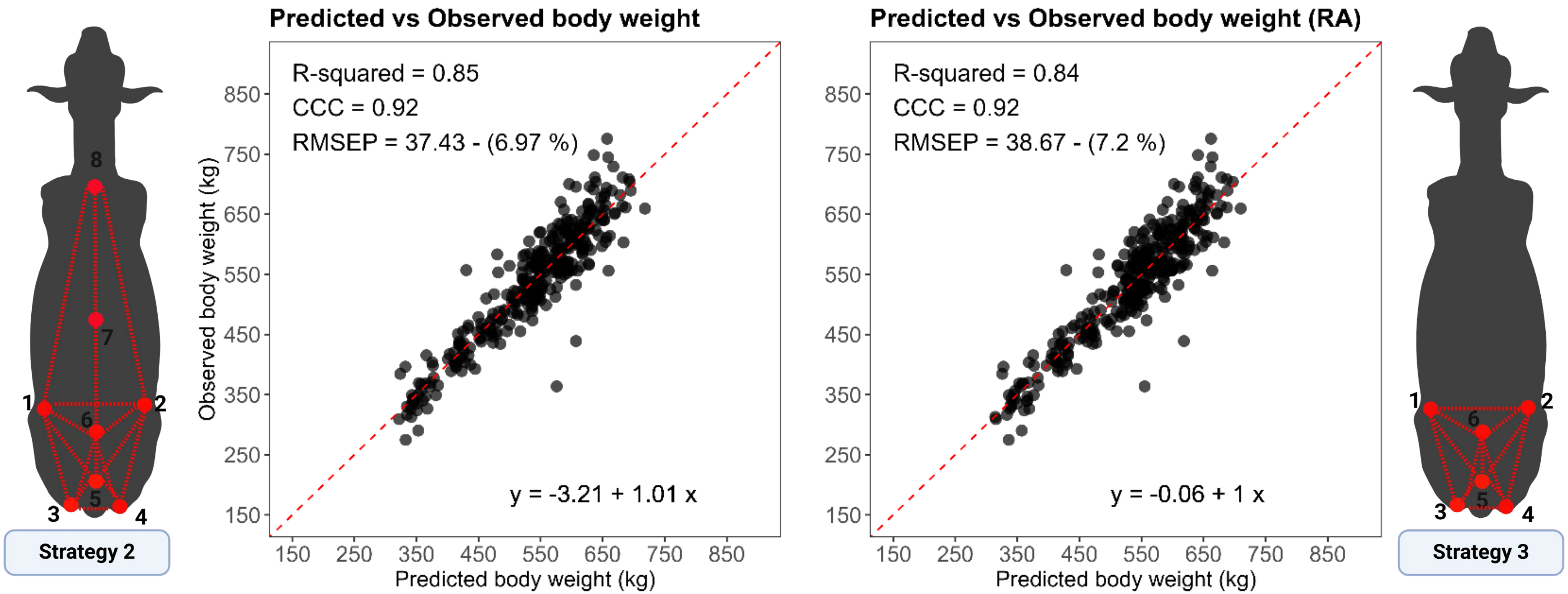
## Computer Vision System at Marshfield – WI (Heifers)

- Edge-computing system with 30 edge devices (3D cameras) ;
- Each camera generates ~10.3 GB per day;
- Until last month: 451.1 TB of data (images)





# Using keypoints for body biometrics




Relationships between predicted and observed variables.

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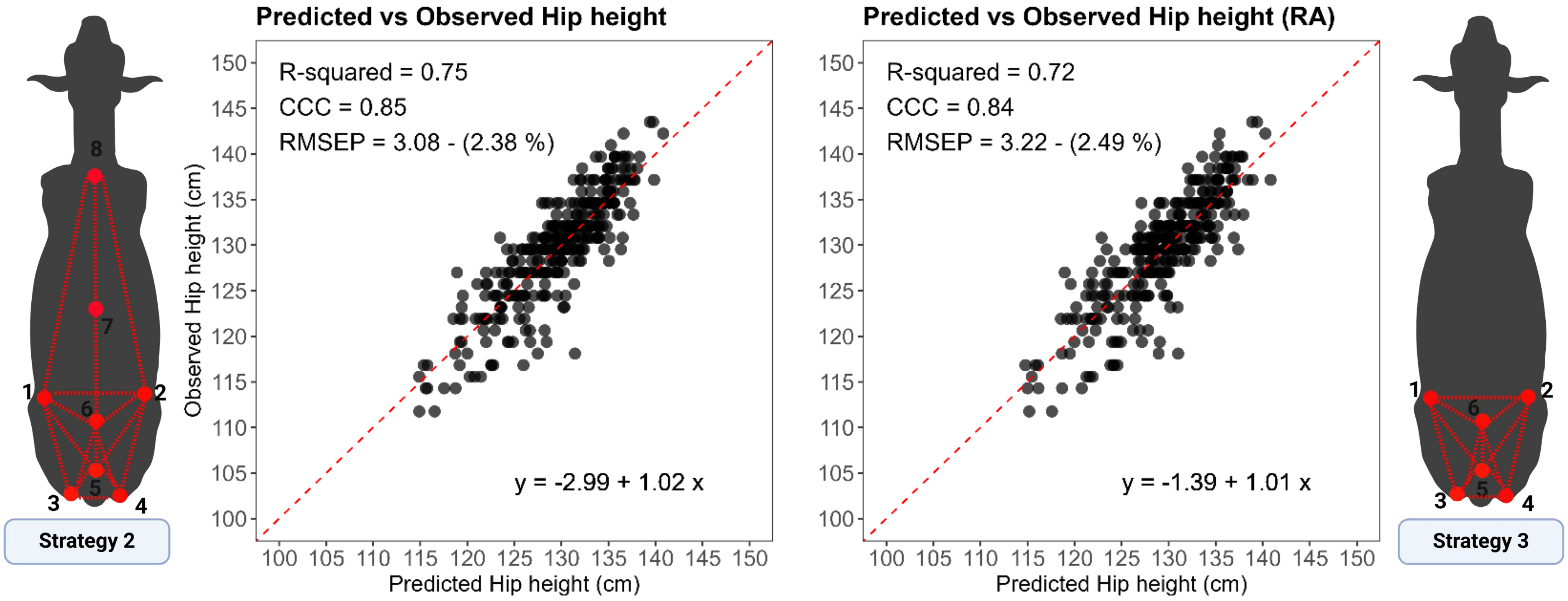
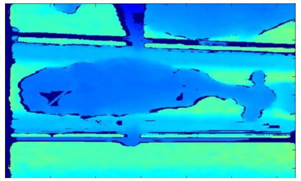



Relationships between predicted and observed variables

# Automation: Cloud-Computing Framework


***Infrared***

***Depth***



***1st Step: Image Classification***

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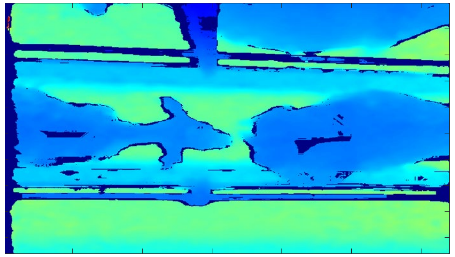
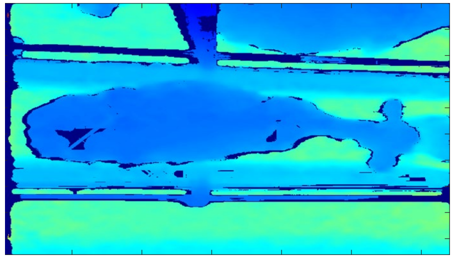


**Good**

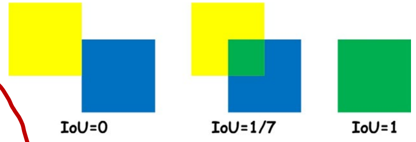


***Xception (Chollet, 2017)***
***2D CNN***
***Accuracy = 97%***
***52,247 total → 19,592 selected***

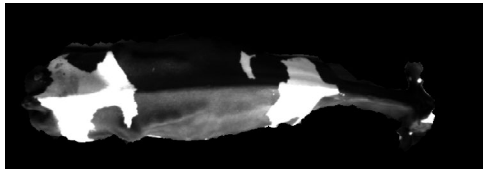
***If good:***

***2nd Step: Image Segmentation (Mask)***

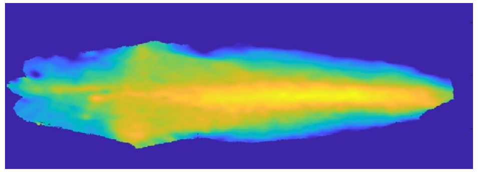
***U-Net (*****Ronneberger et al., 2015*****)***
***2D CNN***
***Intersection Over Union = 0.93***




***3rd Step: Image Identification (Animal Identification)***

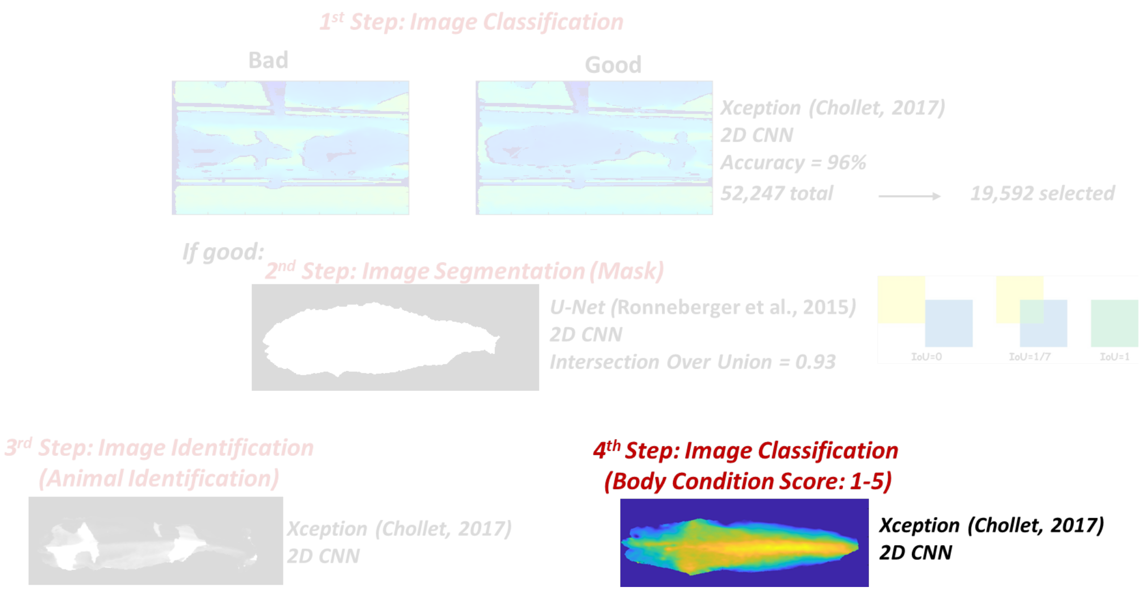


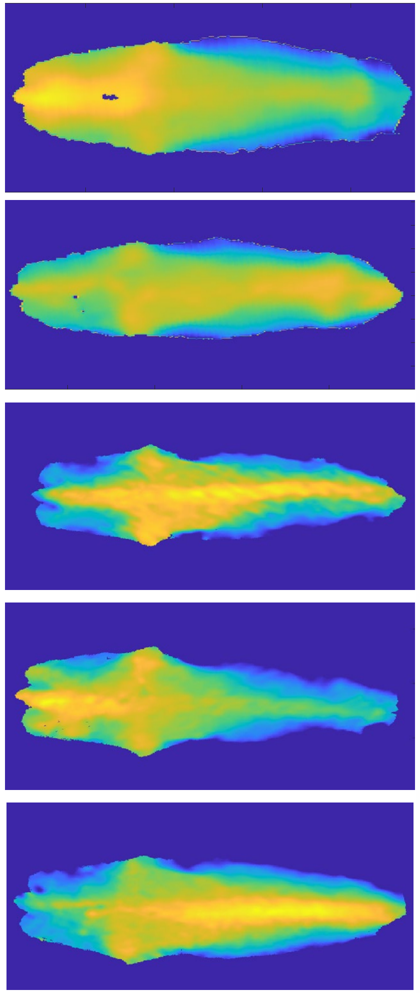
***4th Step: Image Classification (Body Condition Score: 1-5)***



# Body Condition Score using 3D images

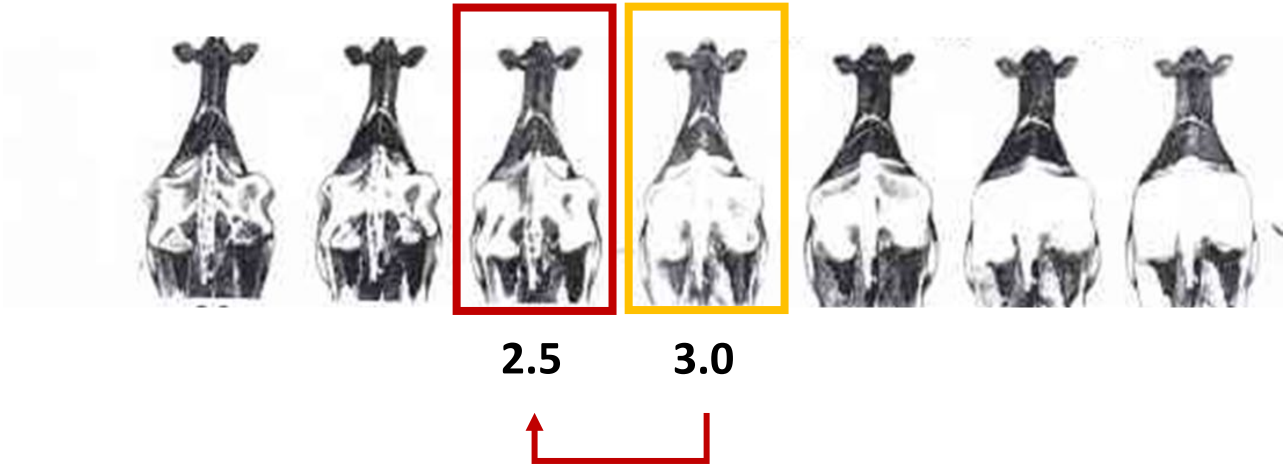
- 59 lactating dairy cows
- Train: 11,943 images
- Test: 651 images
- Deep Learning (CNN; Xception)
- Accuracy (0.25-error): 81% to classify BCS
- Accuracy (0.5-error): 96% to classify BCS

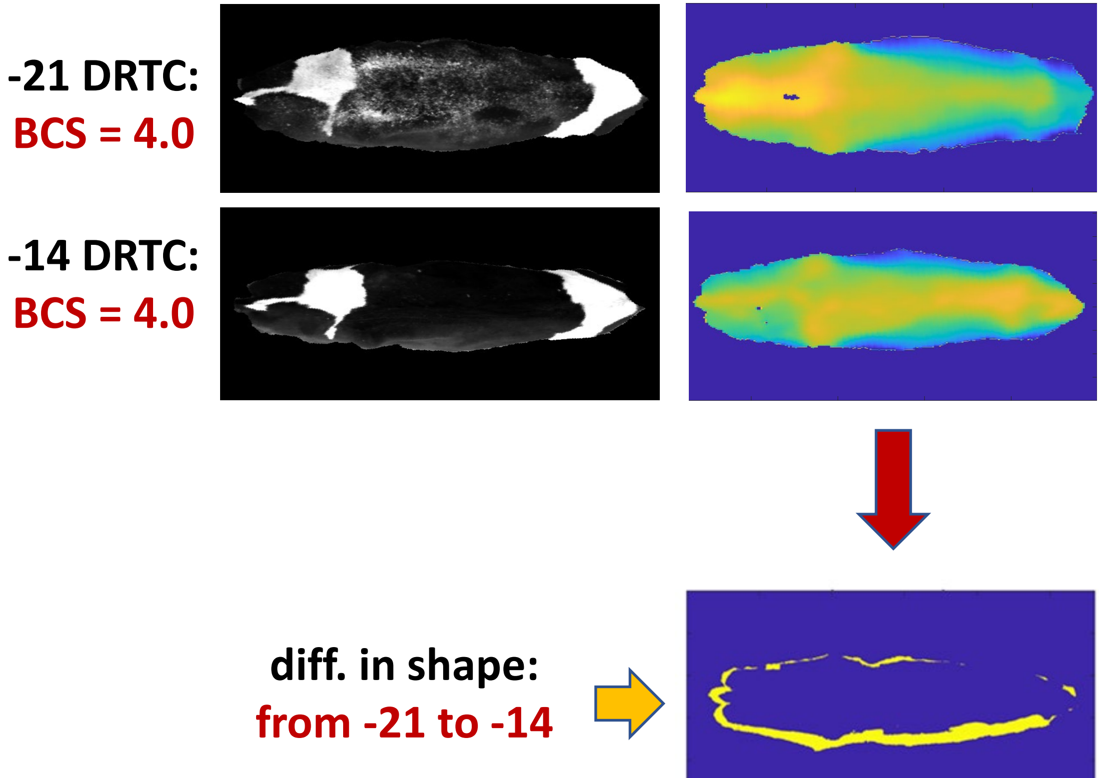


# Subjective and Labor-Intensive

- BCS is a subjective measurement on a 5-point scale that is difficult to measure consistently and systematically in large dairy operations;

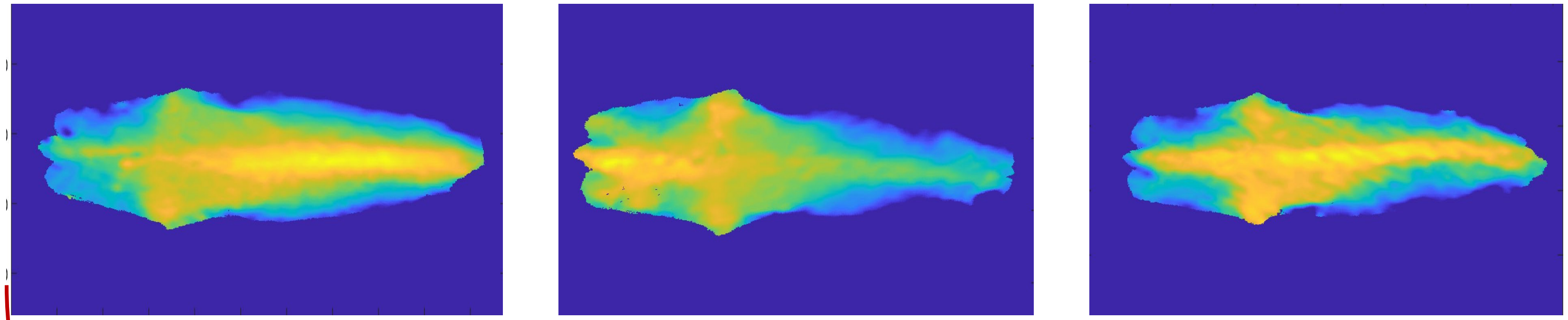



- It requires a trained evaluator to collect BCS information

# Early detection of subclinical ketosis in dairy cows

- Goal: Use prepartum 3D images, wearable sensor, and text to predict subclinical ketosis
- 21, 14 and 7 days prior to calving;
- 92 Holstein cows were individually collected (37 SCK and 55 non-SCK);
- Blood samples were obtained ~every other day from −7 to +21 DRTC,
- Blood BHB values above 1.0 mmol/L postpartum -> subclinical ketosis
- 52,450 top-down 3D images;



Prepartum

Prediction

Subclinical ketosis

1-14 days

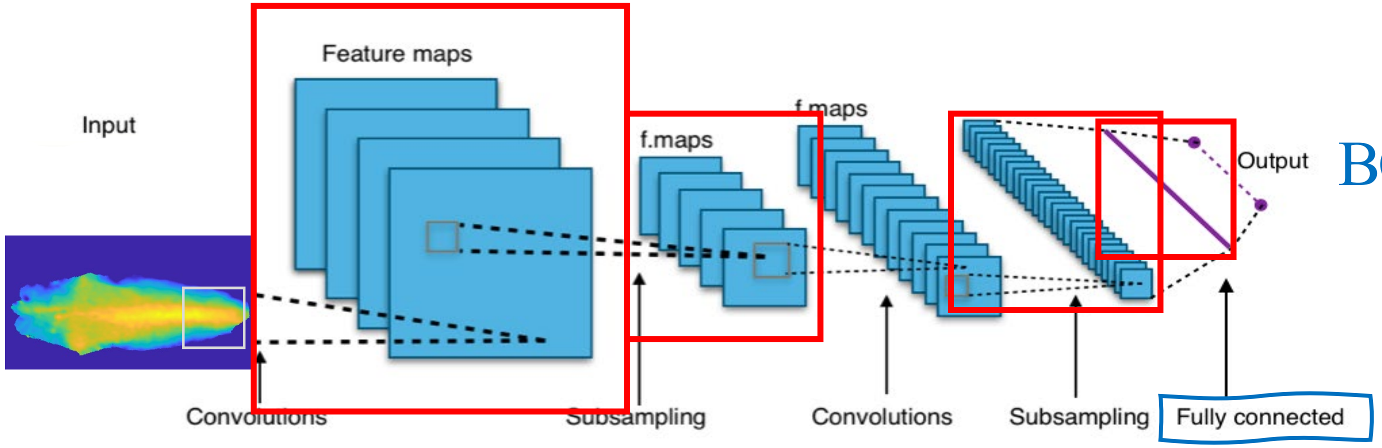
Postpartum

Ferreira et al., 2024 – submitted

# Early detection of subclinical ketosis in dairy cows

For each image:

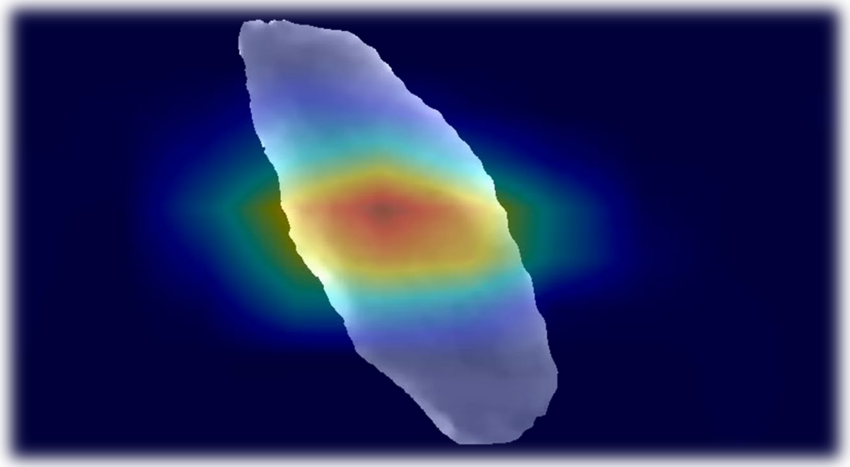
- CNN features (Xception architecture, trained to evaluate BCS)



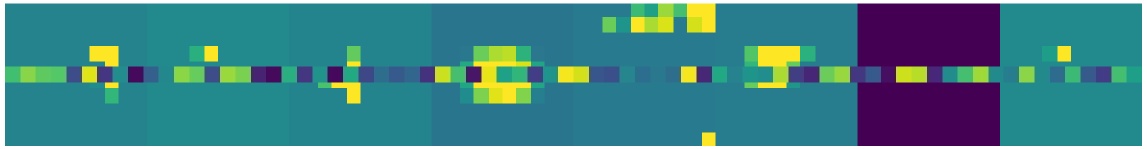

BCS

Xception; Chollet, 2017

1,024 features



CNN Features



Biological + CNN Features: total of 1027 features/ image;

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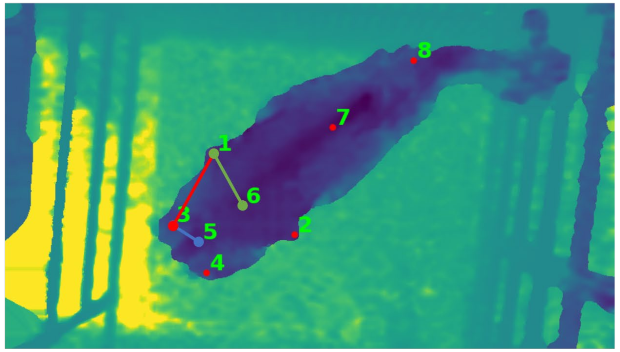
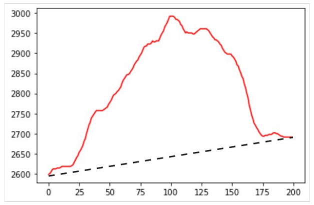
# Early detection of subclinical ketosis in dairy cows

For each image: Biological features (depth vectors)

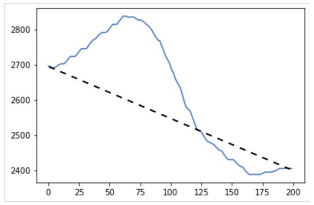
BCS=2.25



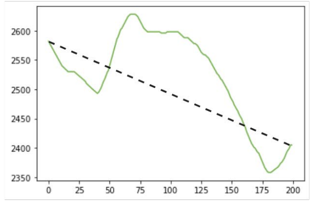

1-3



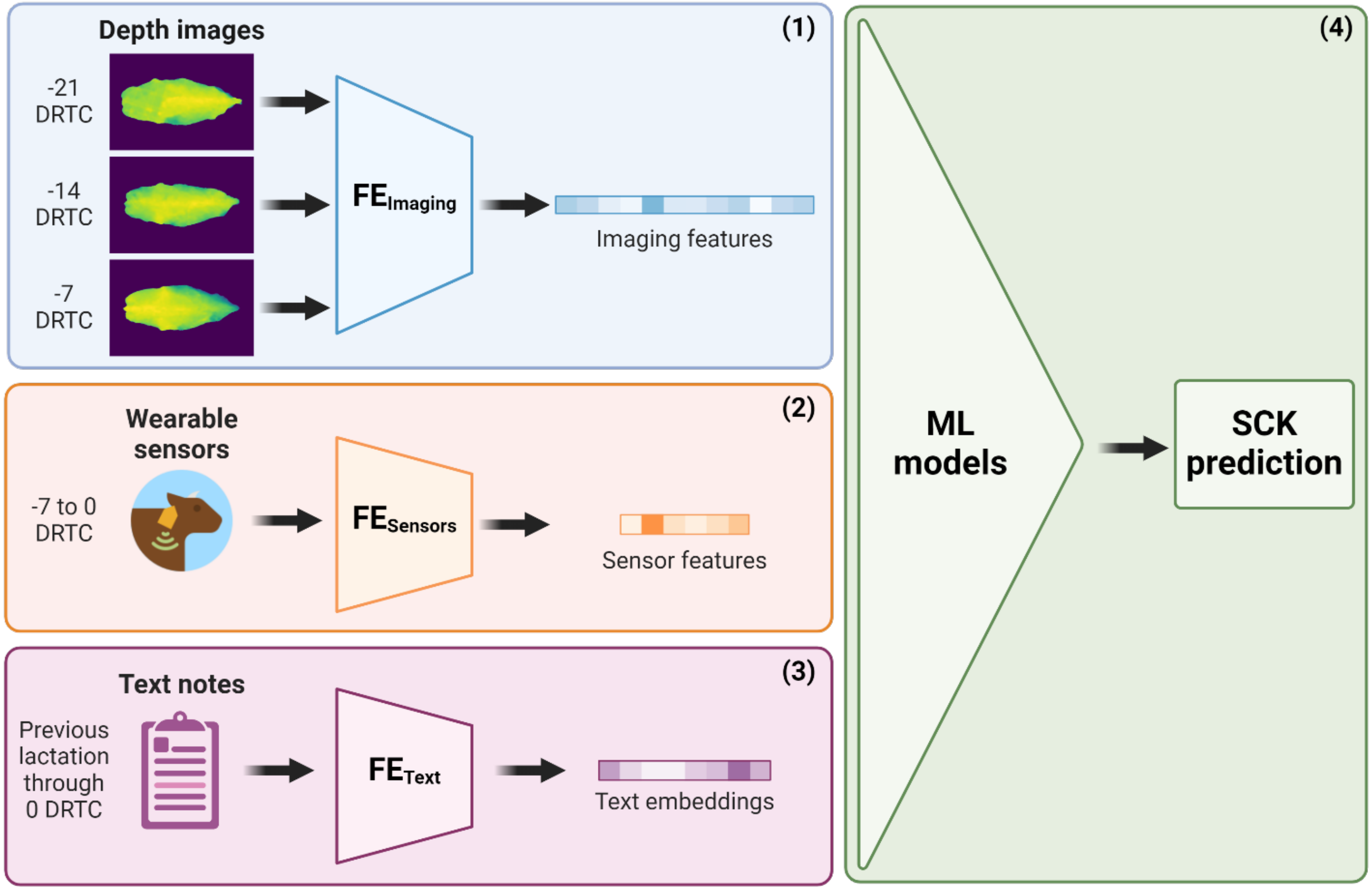

3-5




1-6



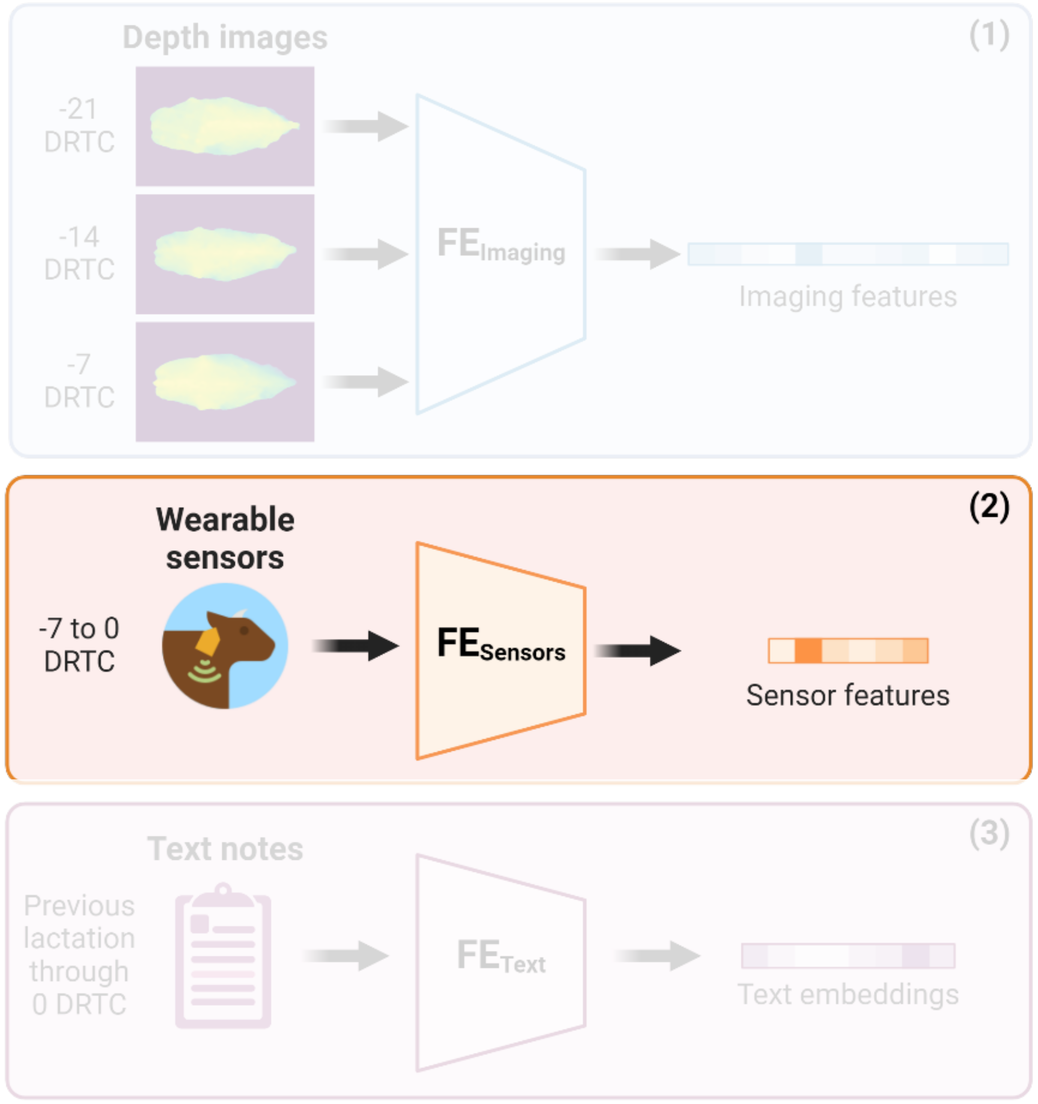
# Early detection of subclinical ketosis in dairy cows

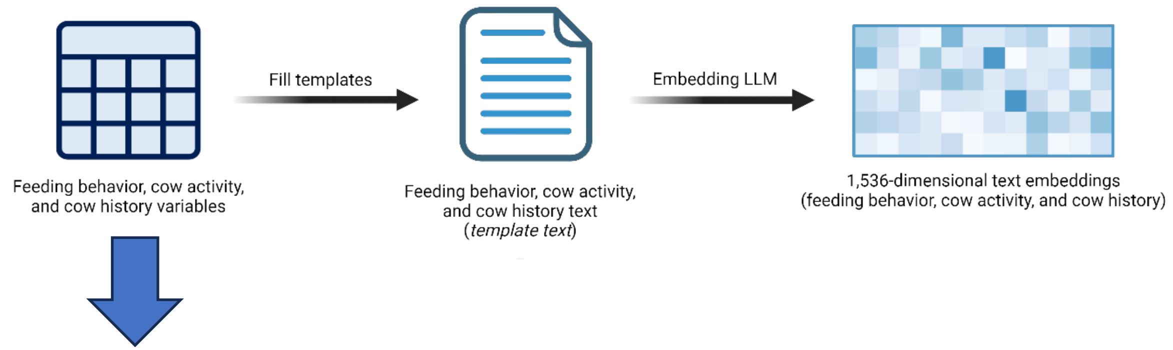



Merging Structured and unstructured data

Ferreira et al., 2024 – submitted

# Early detection of subclinical ketosis in dairy cows



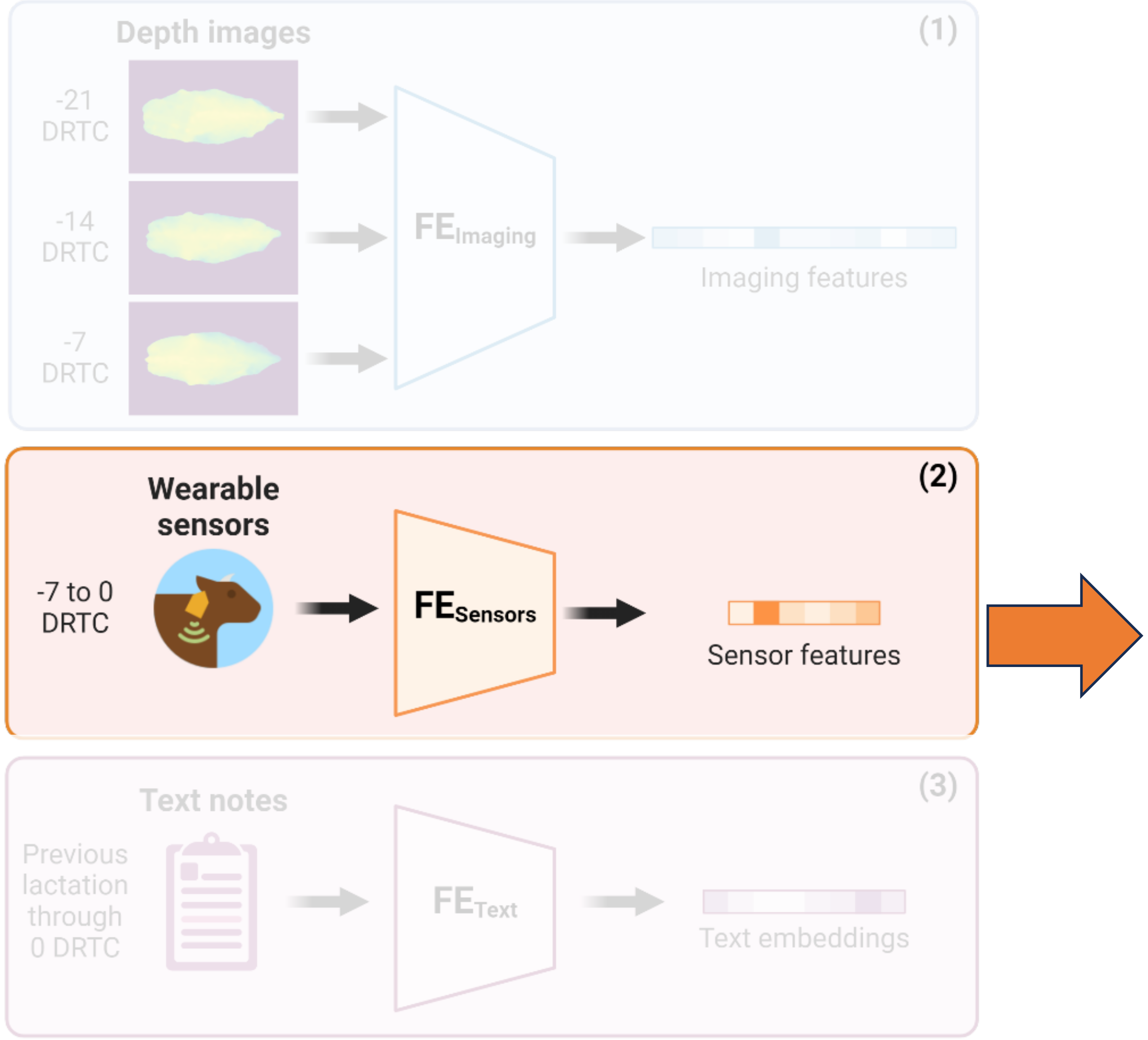



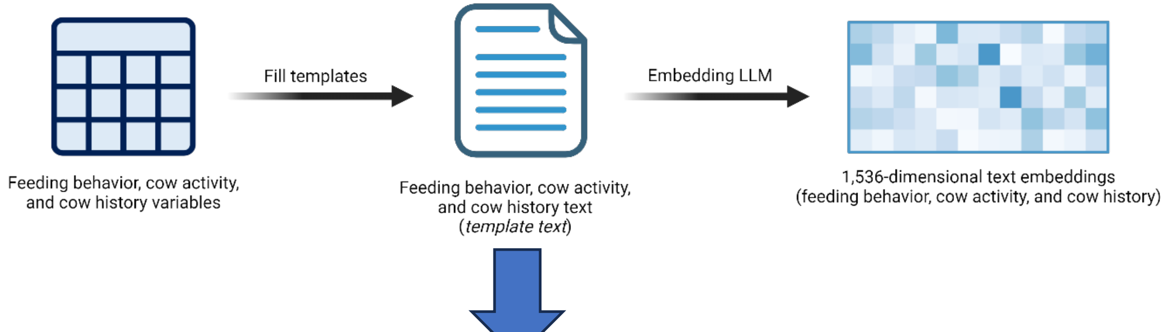

| Cow | DRTC | visits | eating time | Visit duration | time/ meal | … | meals |
|---|---|---|---|---|---|---|---|
| 120 | -21 | 5.91 | 59.31 | 5.91 | 59.31 | | 6 |
| 120 | -20 | 10.56 | 37.38 | 1.32 | 4.67 | | 6 |
| 120 | -19 | 14.27 | 123.70 | 2.37 | 20.61 | | 6 |

+ Rumination, Lying time, Eating time

Ferreira et al., 2024 – submitted

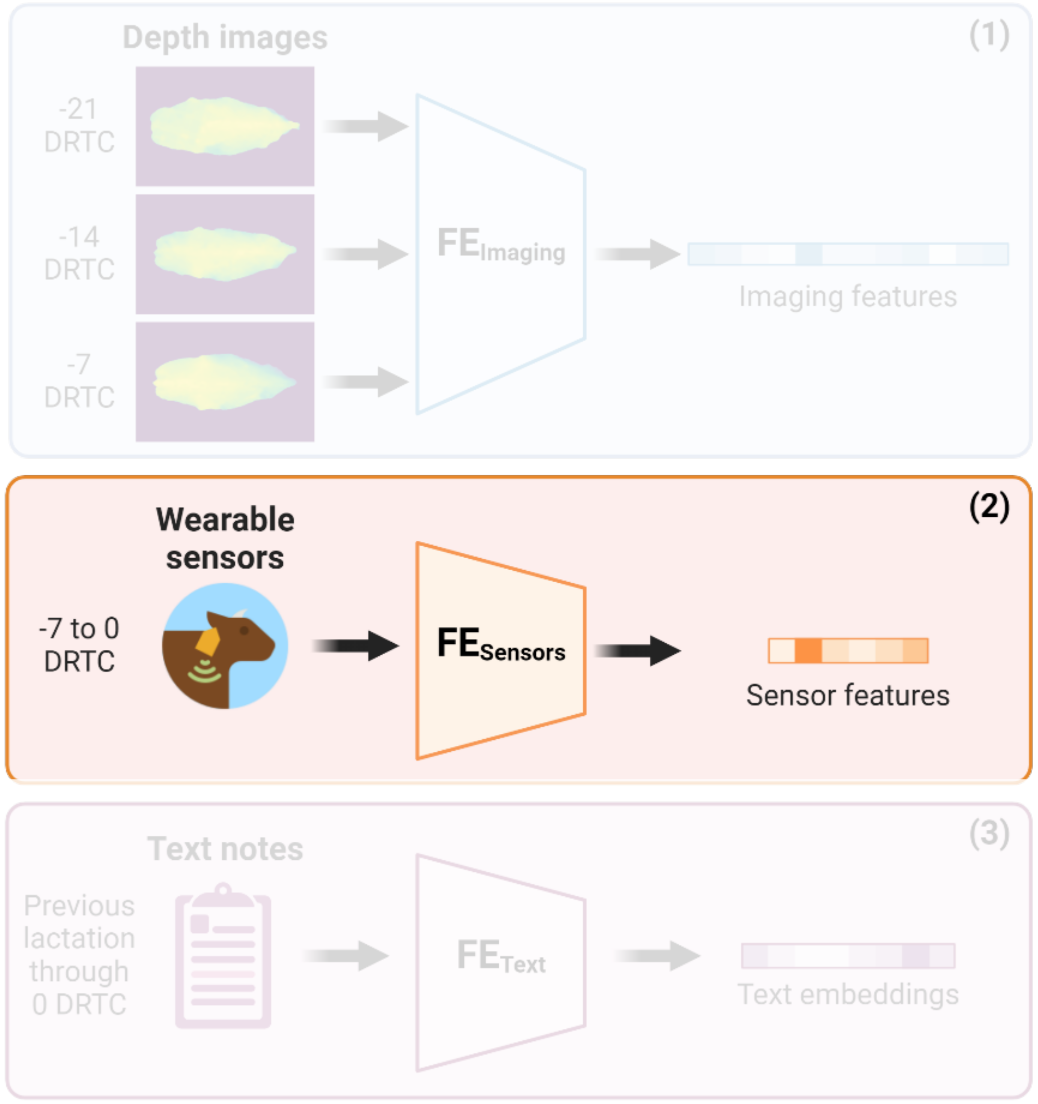
# Early detection of subclinical ketosis in dairy cows

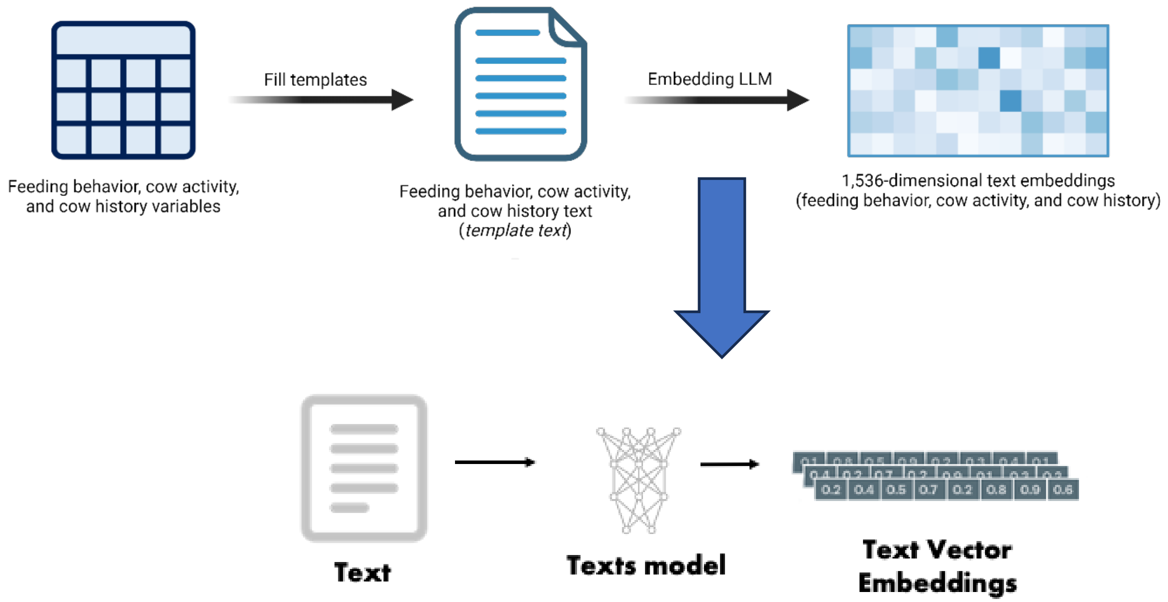



The cow is on its *{Parity}* lactation. Its prior lactation endured a span of *{Previous DIM}* days. It experienced a dry period of *{Previous days dry}* days between the previous and current lactations. It encountered *{Ketosis events}* occurrences of ketosis previously. Its typical daily feeding duration measured an average of *{Feeding time -7}* minutes during the last seven days prepartum and *{Feeding time -2}* minutes during the last two days prepartum. Its meal duration measured an average of *{Meal duration -7}* minutes during the last seven days prepartum and *{Meal duration -2}* minutes during the last two days prepartum. Its daily number of meals measured an average of *{Number of meals -7}* during the last seven days prepartum and *{Number of meals -2}* during the last two days prepartum. In terms of rest and activity, its daily periods spent lying, ruminating, being inactive, and highly active during the week before calving were *{Lying time -7}*, *{Rumination time -7}*, *{Inactive -7}*, and *{Highly active -7}* minutes, respectively. Its body condition score was *{BCS -21}* on 21 days prepartum, *{BCS -14}* on 14 days prepartum, and *{BCS -7}* on 7 days prepartum. Its body weight was *{Body weight -21}* on 21 days prepartum, *{Body weight -14}* on 14 days prepartum, and *{Body weight -7}* on 7 days prepartum.

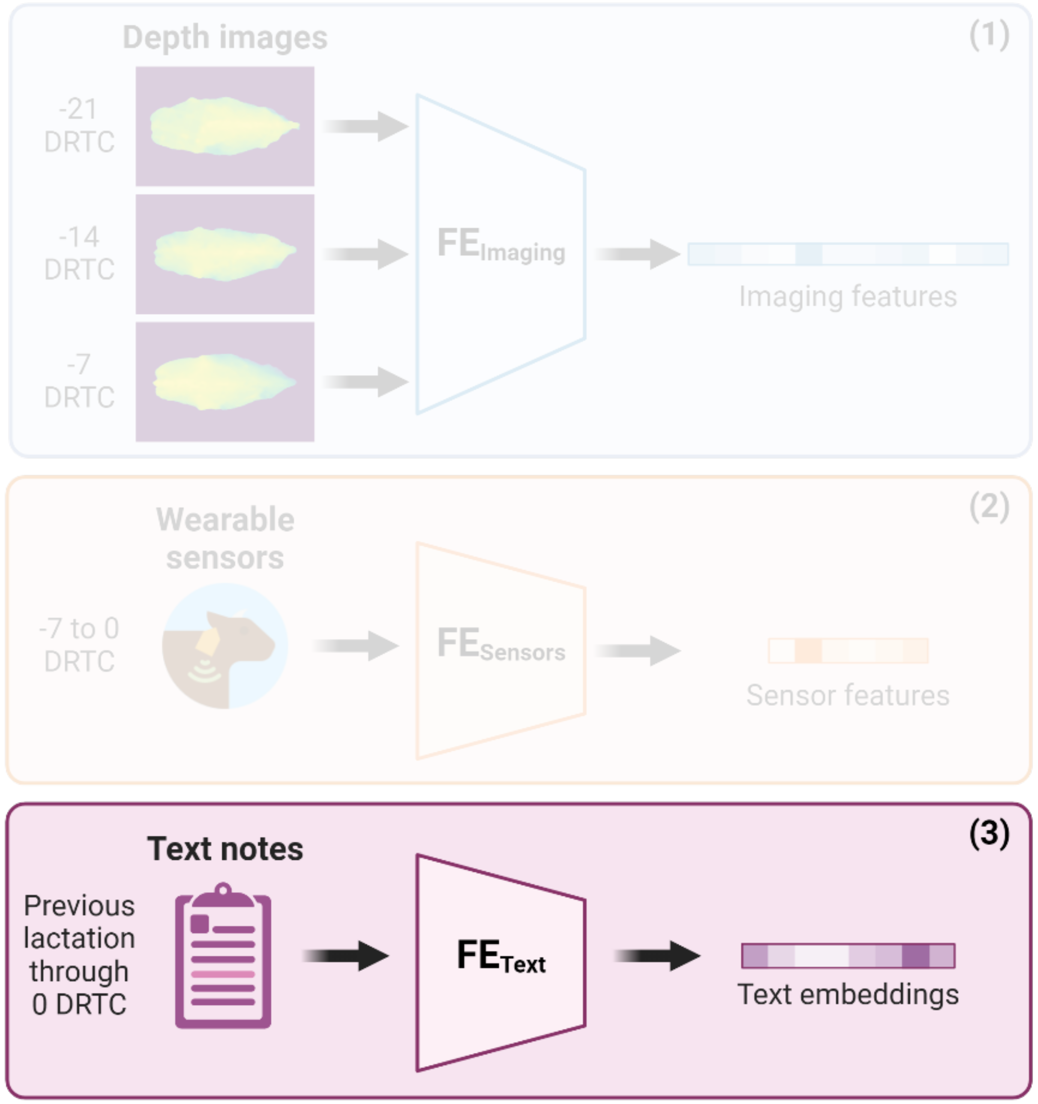
# Early detection of subclinical ketosis in dairy cows




We used 2 LLM:
GPT4.0 for data completion (template generation)
ADA – for embedding extraction (vector db)

# Early detection of subclinical ketosis in dairy cows



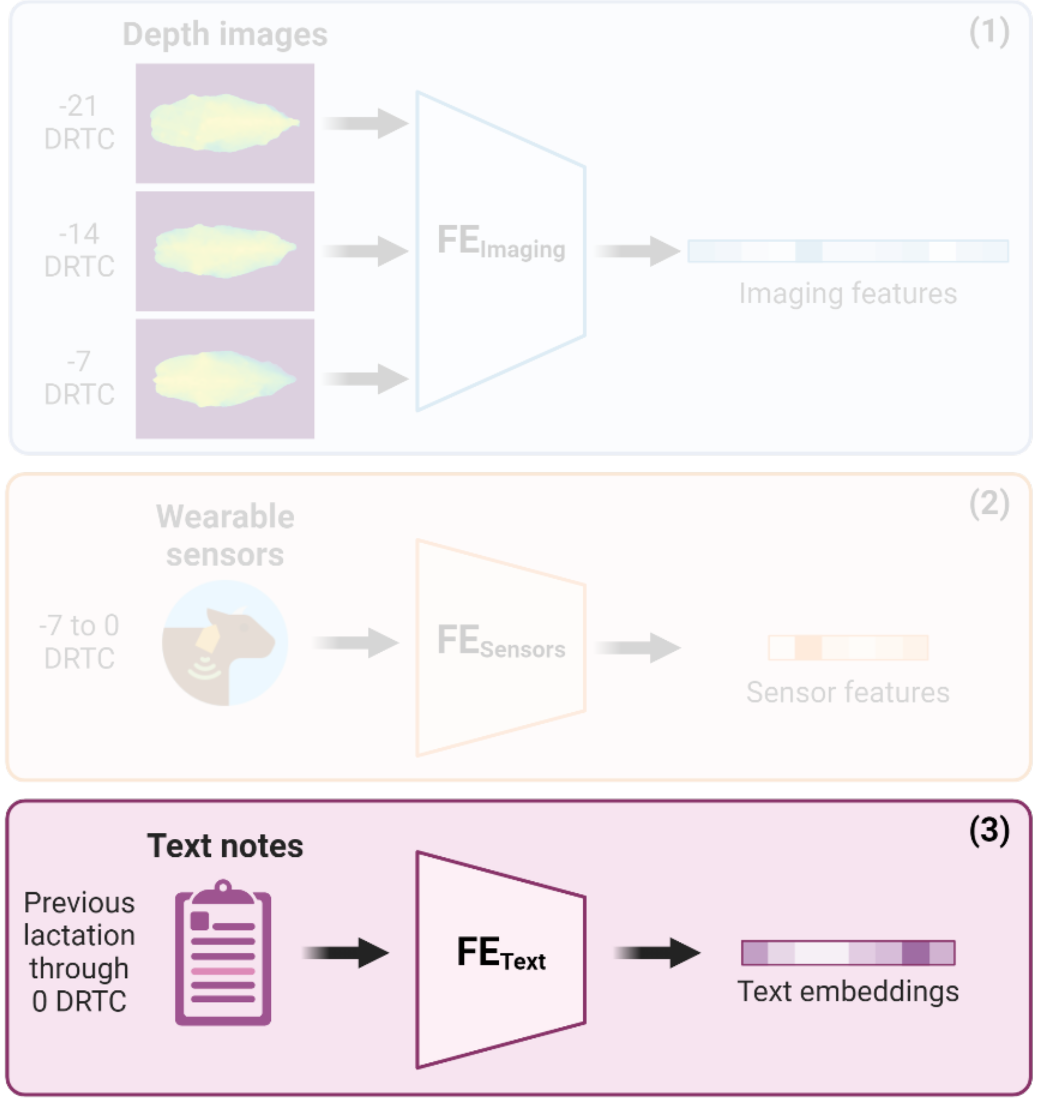

| DATE | EVENT | REMARKS | DETAILS | RESPONSIBLE[1] | DIM | PEN |
|---|---|---|---|---|---|---|
| 9/14/2019 | FRESH | 9762/92 | Heifer 9762 Live | | - | 26 |
| 9/17/2019 | LAME | EXD1.21 | FOOT ROT EXED | | 3 | 9 |
| 12/5/2019 | BRED | 511H12240 | Open (O), Double Ovsynch (D) | Rafael | 82 | 34 |
| 1/6/2020 | RECHK | LOSING? | - | | 114 | 34 |
| 1/13/2020 | OPEN | LUT2CLEA | - | | 121 | 34 |
| 1/20/2020 | NOTES | CIDR | - | | 128 | 34 |
| 1/27/2020 | OK | LUT | - | | 135 | 34 |
| 1/30/2020 | BRED | 629H18813 | Open (O), LUT (L) | Joao | 138 | 34 |
| 3/2/2020 | OPEN | LUT | - | | 170 | 34 |
| 3/5/2020 | BRED | 11AN1212 | Open (O), Resynch 25 (T) | Rafael | 173 | 34 |
| 4/6/2020 | OPEN | CL RIGHT | - | | 205 | 34 |
| 4/9/2020 | BRED | 29AN1993 | Open (O), Resynch 25 (T) | Joao | 208 | 34 |
| 5/11/2020 | OPEN | LUT | - | | 240 | 34 |
| 5/14/2020 | BRED | 829AN1868 | Pregnant (P), Resynch 25 (T) | Joao | 243 | 34 |
| 6/15/2020 | PREG | ROCL | - | | 275 | 34 |
| 6/29/2020 | PREG | ROCL | - | | 289 | 34 |
| 7/1/2020 | MOVE | TOMARS | - | | 291 | 34 |
| 7/17/2020 | LAME | LATDRH | Dig Derm - Wa | | 307 | 94 |
| 7/20/2020 | PREG | HEIFER | - | | 310 | 94 |
| 9/14/2020 | PREG | 123 Days | - | | 366 | 94 |
| 12/27/2020 | MOVE | F094T168 | 94 → 168 | | 470 | 94 |
| 12/30/2020 | DRY | SPCDC | SPECTRA-DC.IM | | 473 | 168 |
| 1/6/2021 | MOVE | TO ARL | - | | 480 | 168 |
| 1/26/2021 | MOVE | CLOSEUP | - | | 500 | 38 |
| 1/26/2021 | ONEXP | HMW618 | - | | 500 | 26 |
| 2/2/2021 | NOTES | URINE 5.5 | - | | 507 | 26 |

(a) CSV file containing all the notes taken during the previous lactation

```
The chronological report of events for the cow described in the CSV is as follows:

1. **September 14, 2019**: The cow entered the herd as a fresh heifer (9762/92). This event happened in pen 26.
2. **September 17, 2019**: The cow was diagnosed as lame due to foot rot (EXD1.21) on day 3 of lactation in pen 9.
3. **December 5, 2019**: The cow was bred by Rafael using semen from bull 511H12240 with the method "Open (O), Double Ovsynch (D)" on day 82 of lactation in pen 34.
4. **January 6, 2020**: A recheck (RECHK) indicated a possible issue ("LOSING?") on day 114 in pen 34.
5. **January 13, 2020**: The cow was confirmed open with a treatment of LUT2CLEA on day 121 in pen 34.
6. **January 20, 2020**: Notes indicate a CIDR intervention on day 128 in pen 34.
7. **January 27, 2020**: The cow was OK'd following LUT treatment on day 135 in pen 34.
8. **January 30, 2020**: The cow was bred by Joao using semen from bull 629H18813 with the method "Open (O), LUT (L)" on day 138 in pen 34.
9. **March 2, 2020**: The cow was confirmed open following LUT treatment on day 170 in pen 34.
10. **March 5, 2020**: The cow was bred by Rafael using semen from bull 11AN1212 with the method "Open (O), Resynch 25 (T)" on day 173 in pen 34.
11. **April 6, 2020**: The cow was confirmed open with a note of "CL RIGHT" on day 205 in pen 34.
12. **April 9, 2020**: The cow was bred by Joao using semen from bull 29AN1993 with the method "Open (O), Resynch 25 (T)" on day 208 in pen 34.
13. **May 11, 2020**: The cow was confirmed open following LUT treatment on day 240 in pen 34.
14. **May 14, 2020**: The cow was bred by Joao using semen from bull 829AN1868 with the method "Pregnant (P), Resynch 25 (T)" on day 243 in pen 34.
15. **June 15, 2020**: Pregnancy confirmed (ROCL) on day 275 in pen 34.
16. **June 29, 2020**: Another pregnancy check confirmed (ROCL) on day 289 in pen 34.
17. **July 1, 2020**: The cow was moved to Mars on day 291 in pen 34.
18. **July 17, 2020**: The cow was diagnosed as lame due to digital dermatitis (Dig Derm - Wa) on day 307 in pen 94.
19. **July 20, 2020**: Pregnancy confirmed with a note of "HEIFER" on day 310 in pen 94.
20. **September 14, 2020**: Pregnancy progression noted as 123 days on day 366 in pen 94.
21. **December 27, 2020**: The cow was moved from pen 94 to 168 on day 470.
22. **December 30, 2020**: The cow was dried off with SPECTRA-DC.IM on day 473 in pen 168.
23. **January 6, 2021**: The cow was moved to ARL on day 480 in pen 168.
24. **January 26, 2021**: The cow was moved to the close-up pen on day 500 in pen 38 and also noted for on-experiment with HMW618 in pen 26.
25. **February 2, 2021**: Notes indicate a urine pH of 5.5 on day 507 in pen 26.

This report tracks the cow's journey through various health checks, breeding attempts, pregnancy confirmations, and management changes throughout her lactation period.

The cow's current lactation, for which we want to predict the risk of subclinical ketosis, started on February 13, 2021.
```

(b) Free text generated from the CSV file using OpenAI's chat completion API

# Early detection of subclinical ketosis in dairy cows

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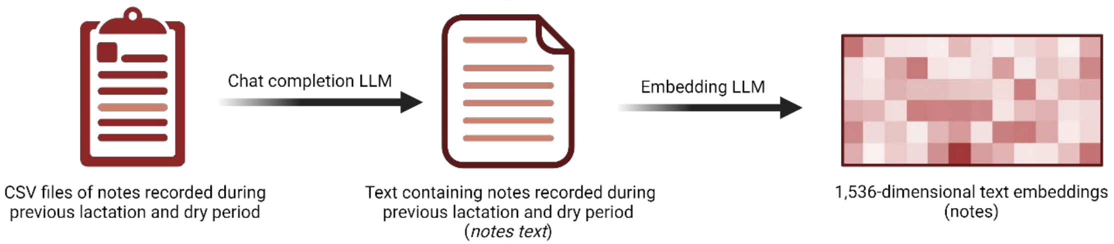


# Early detection of subclinical ketosis in dairy cows

## Few Considerations:

The resulting model achieved an average $F_1$ score of 0.68 and average Accuracy of 76.1% (using Random Forest) –

*early detection of subclinical ketos (at least 7 days in advance)

Unstructured vs Structured data:

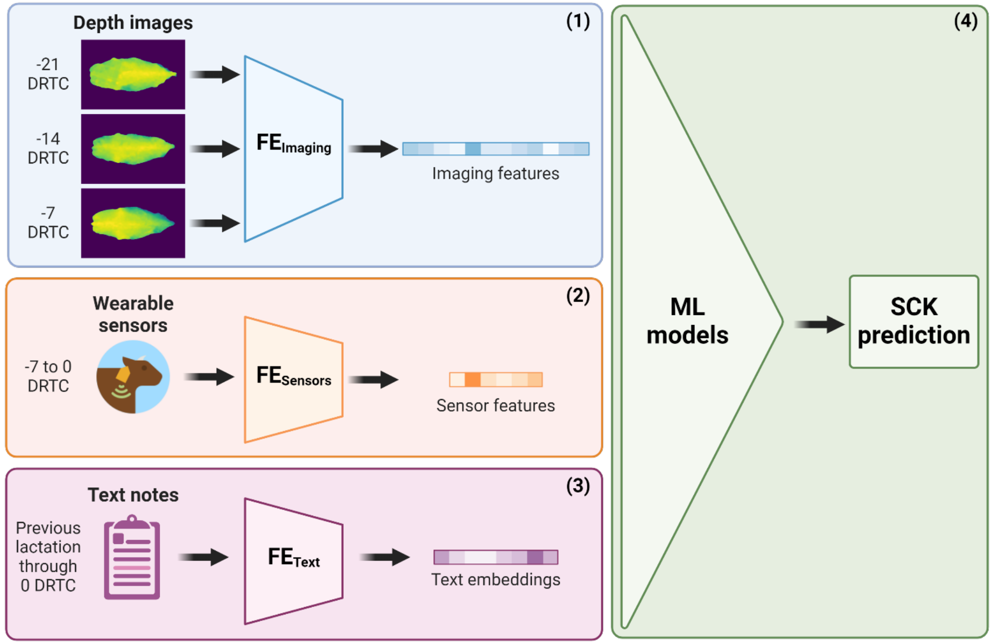
average F1 score = 0.60 vs 0.65

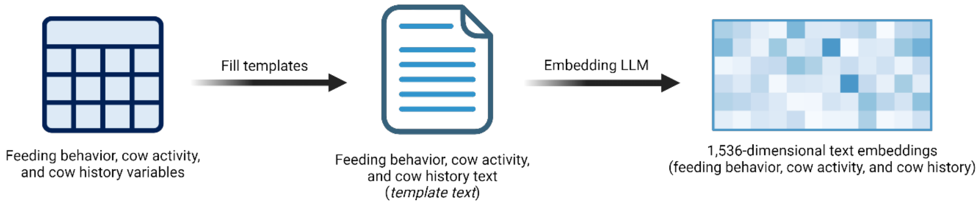
average accuracy = 70% vs 74%

*embedding model not fine-tuned in our data(text) context

Adding unstructured notes increased the average F1-score and accuracy of the model

*relevant information on the notes

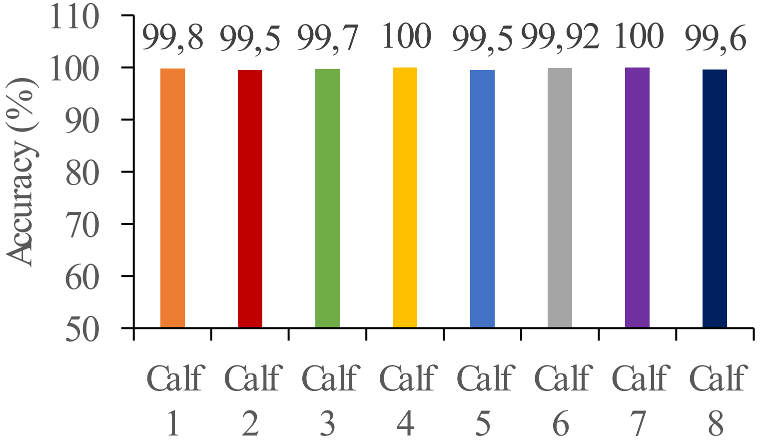



Next Steps: Economic Evaluation / Longer Time-Series (-60 DIM)

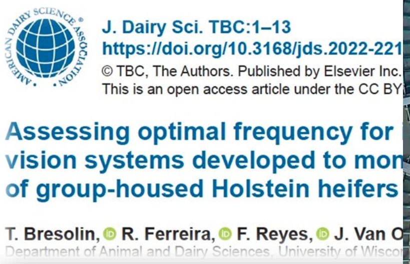
# Monitoring Feeding Behavior

- 1,546 images were used to train a deep learning algorithm for object detection (YOLOv3);
- 663 extra images were used for testing




The $R^2$ between observed and predicted:

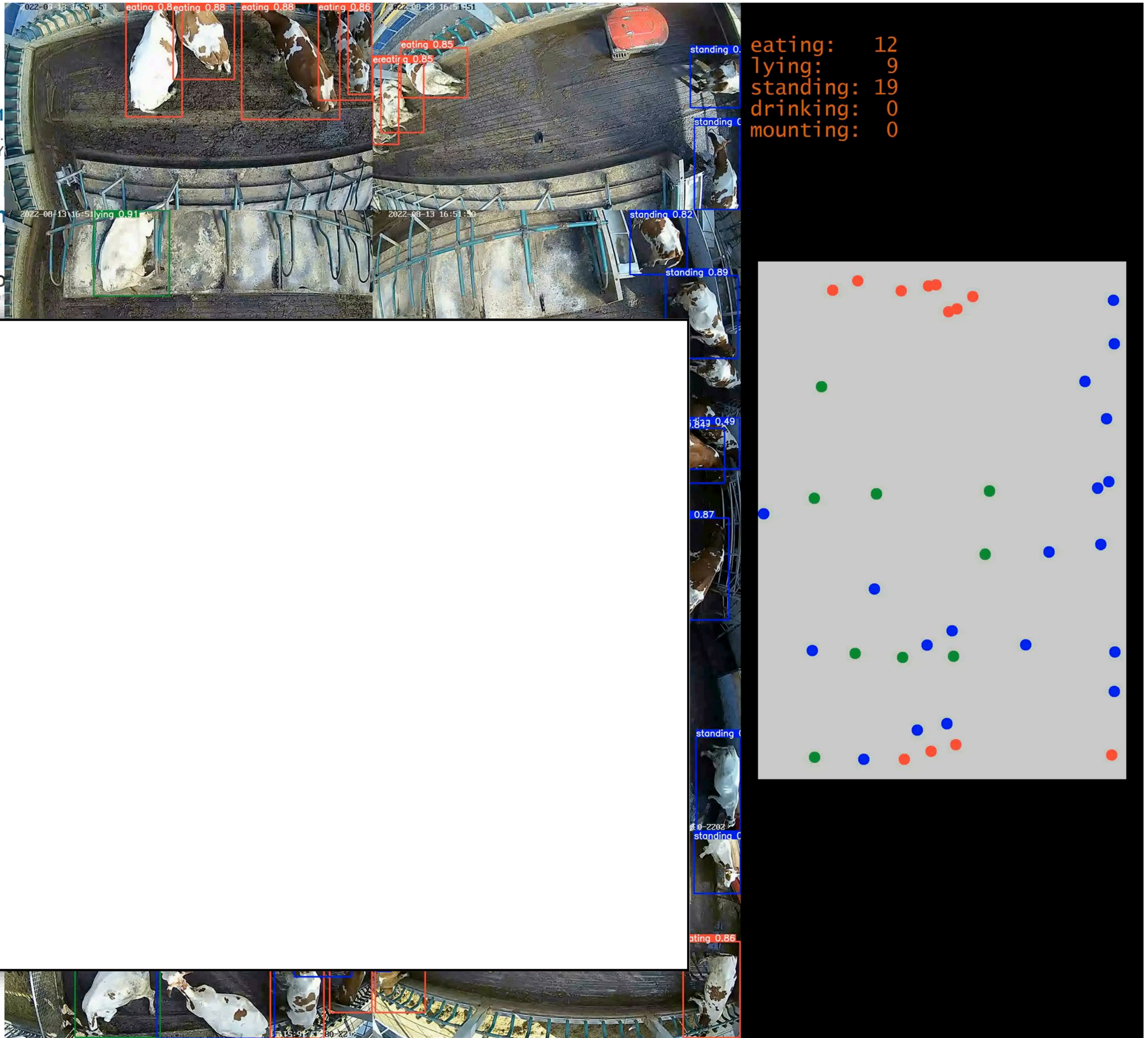
- Total eating time: 0.99
- Visit duration: 0.77
- Interval between visits: 0.70
- Visits: 0.55



J. Dairy Sci. TBC:1–13
https://doi.org/10.3168/jds.2022-221


Assessing optimal frequency for
vision systems developed to mon
of group-housed Holstein heifers

T. Bresolin, R. Ferreira, F. Reyes, J. Van O
Department of Animal and Dairy Sciences, University of Wisco

# Animal Health: Heat-Stress

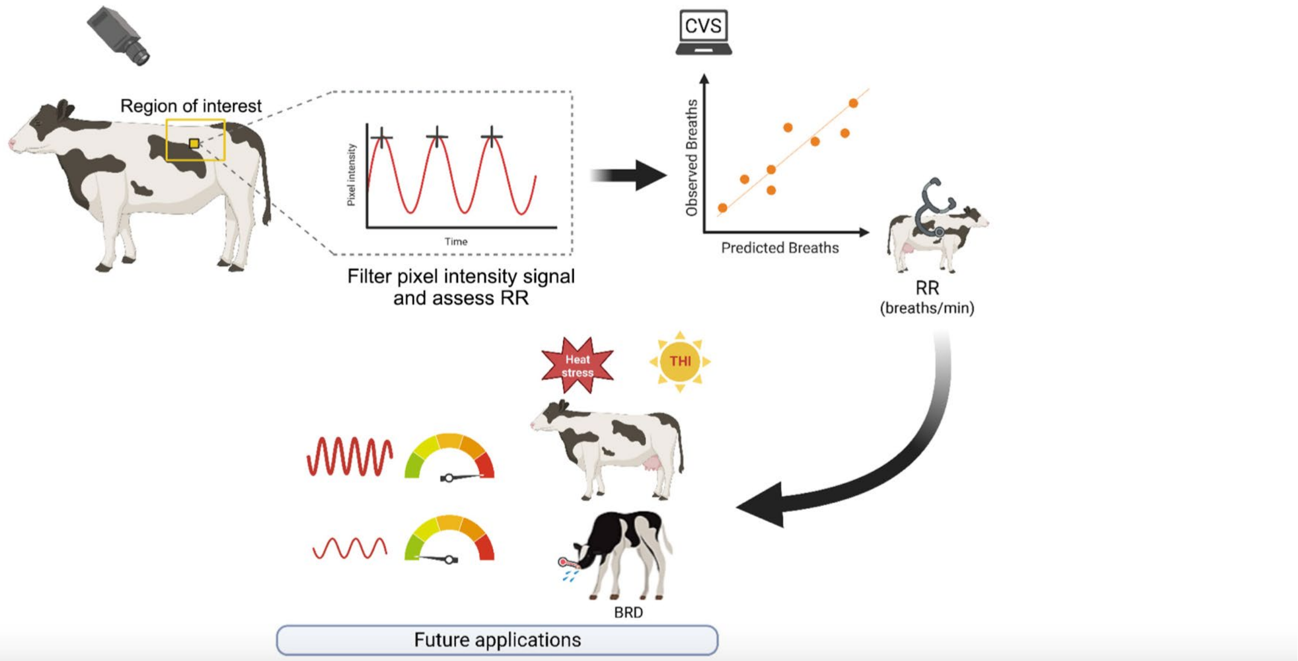
JDS Communications®
2024; 5:310–316

https://doi.org/10.3168/jdsc.2023-0442
Short Communication
Health, Welfare, and Behavior

## Predicting respiration rate in unrestrained dairy cows using image analysis and fast Fourier transform

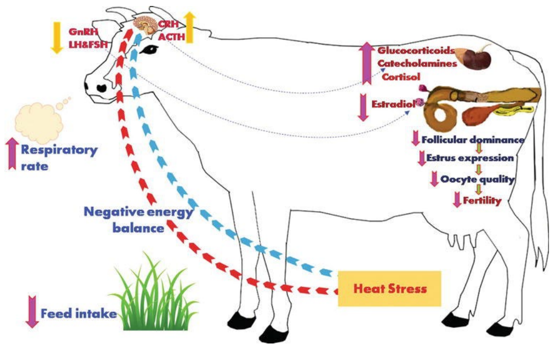
Raphael R. Mantovani,[1] Guilherme L. Menezes,[1] and João R. R. Dórea[1,2]*

### Graphical Abstract

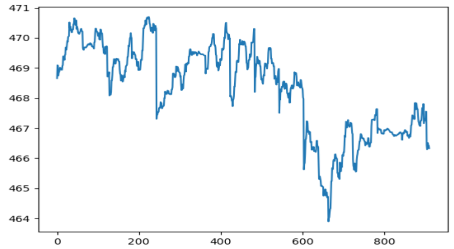



Mantovani et al., 2024

# Animal Health: Heat-Stress



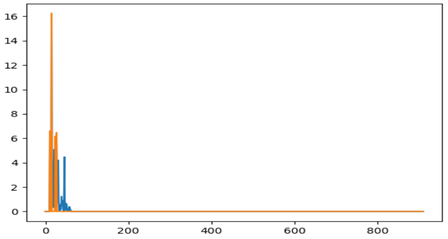

**Pixel intensity (original domain)**



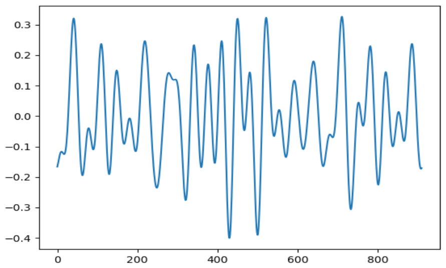
**Fast Fourier Transform**

$$x[k] = \sum_{n=0}^{N-1} x[n] e^{\frac{-j2\pi kn}{N}}$$

**Frequency Domain**



**Adjusted pixel intensity (Transformed)**




Mantovani et al., 2024

# Predictive Performance – Respiration Rate

JDS Communications®
2024; 5:310–316
https://doi.org/10.3168/jdsc.2023-0442
Short Communication
Health, Welfare, and Behavior

**Predicting respiration rate in unrestrained dairy cows using image analysis and fast Fourier transform**

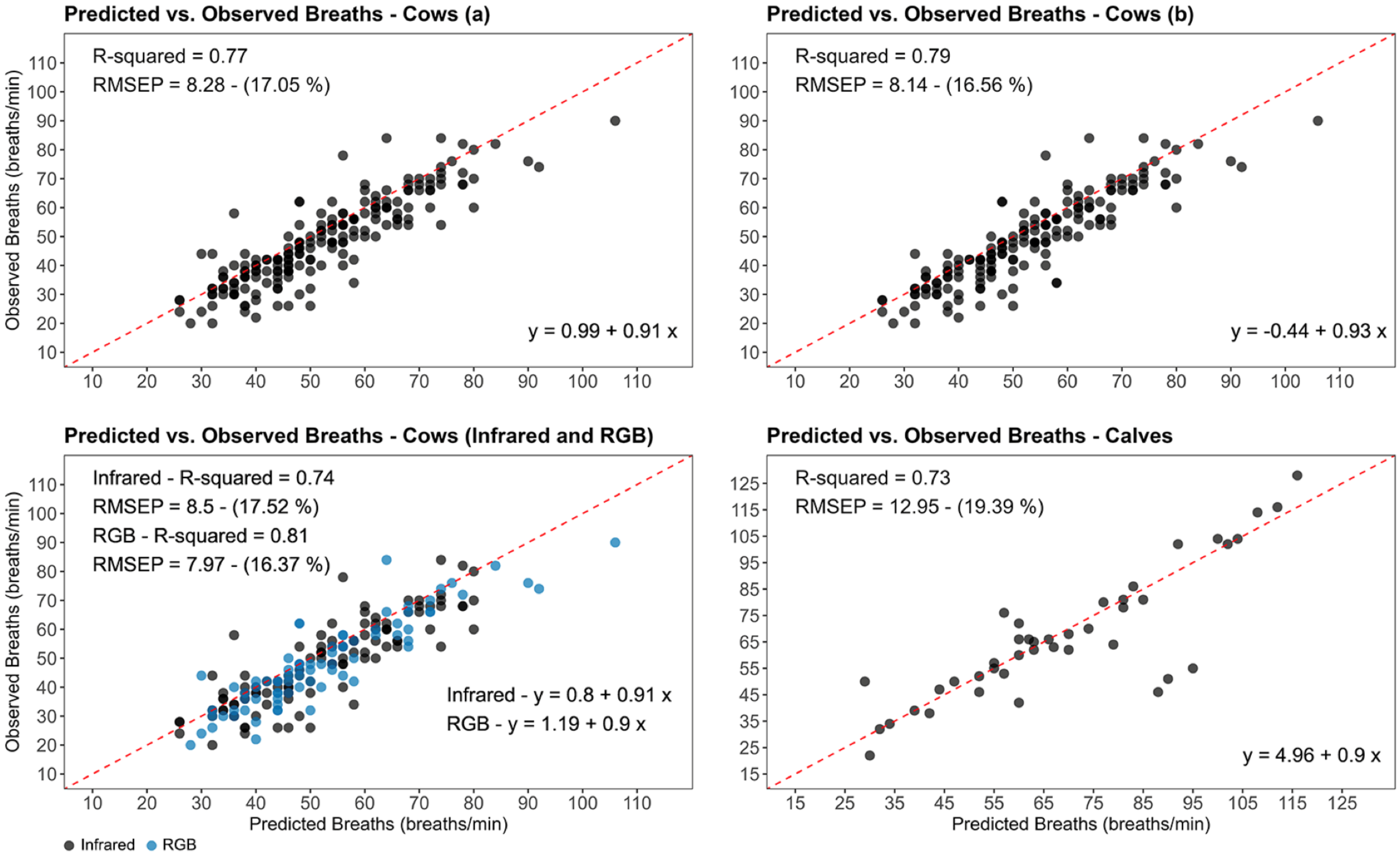
Raphael R. Mantovani,[1] Guilherme L. Menezes,[1] and João R. R. Dórea[1,2]*

- 168 videos:
(30-seconds segments)
from 32 cows

- 42 videos from 25 calves

- Infrared images (night period)

- RGB images (day period)



# Locomotion Problems

Computers and Electronics in Agriculture
Volume 217, February 2024, 108573

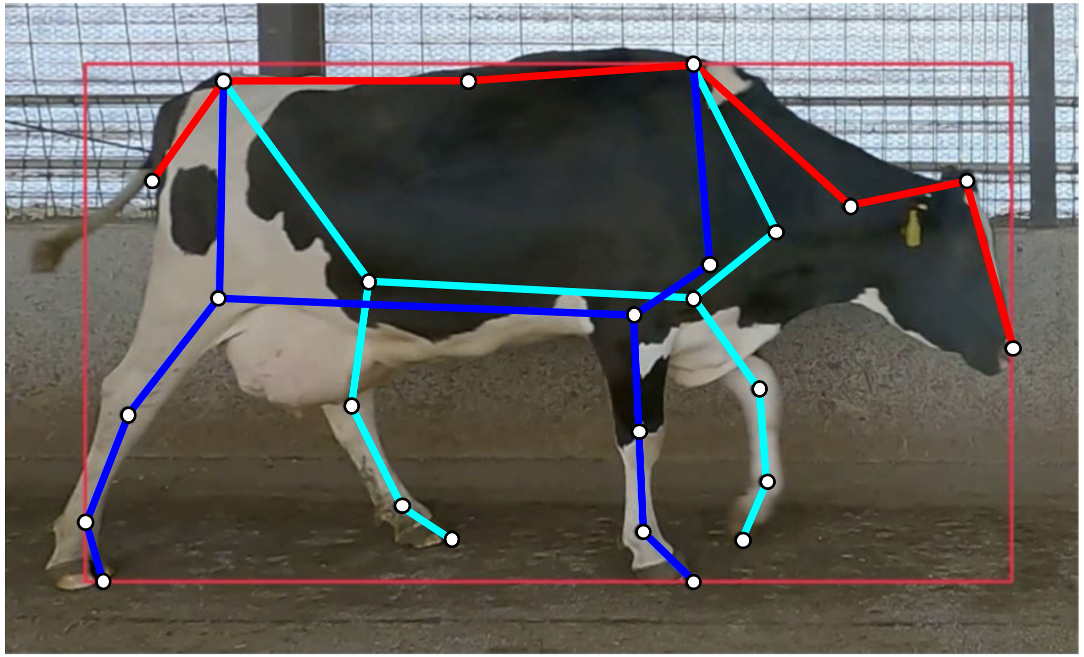
## Leveraging computer vision-based pose estimation technique in dairy cows for objective mobility analysis and scoring system

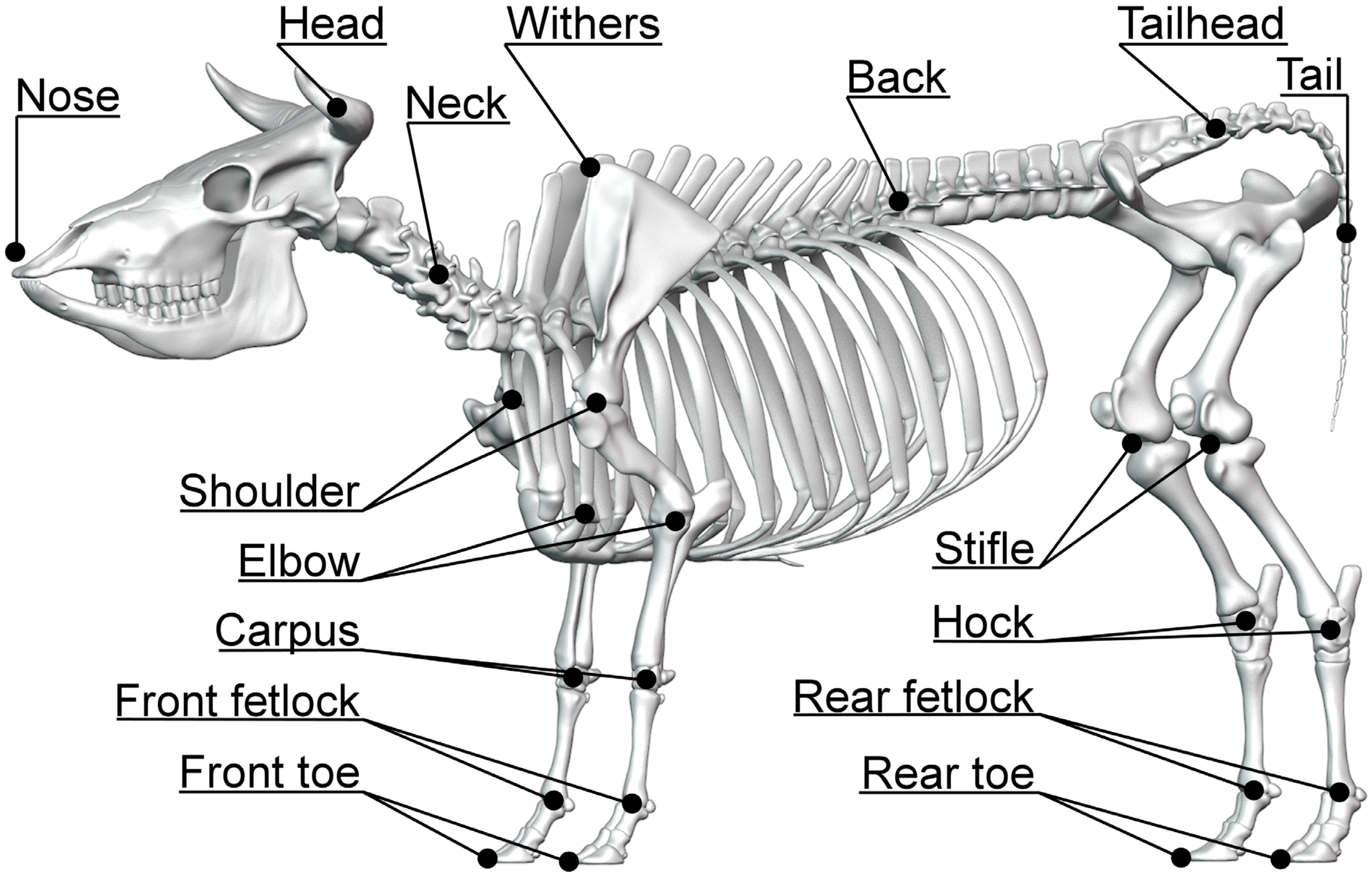
Shogo Higaki [a] [b], Yoshitaka Matsui [c], Masafumi Miwa [d], Takashi Yamamura [e], Takuo Hojo [f], Koji Yoshioka [g], Alysia Vang [b], Ariana Negreiro [b], João R.R. Dórea [b]

Training dataset = 9,003 images (9,000 animals)

Test dataset = 970 images (1,432 animals)

Performance = 8.79 ± 2.20 pixels (Euclidean distance)





# Mobility variables

ELSEVIER

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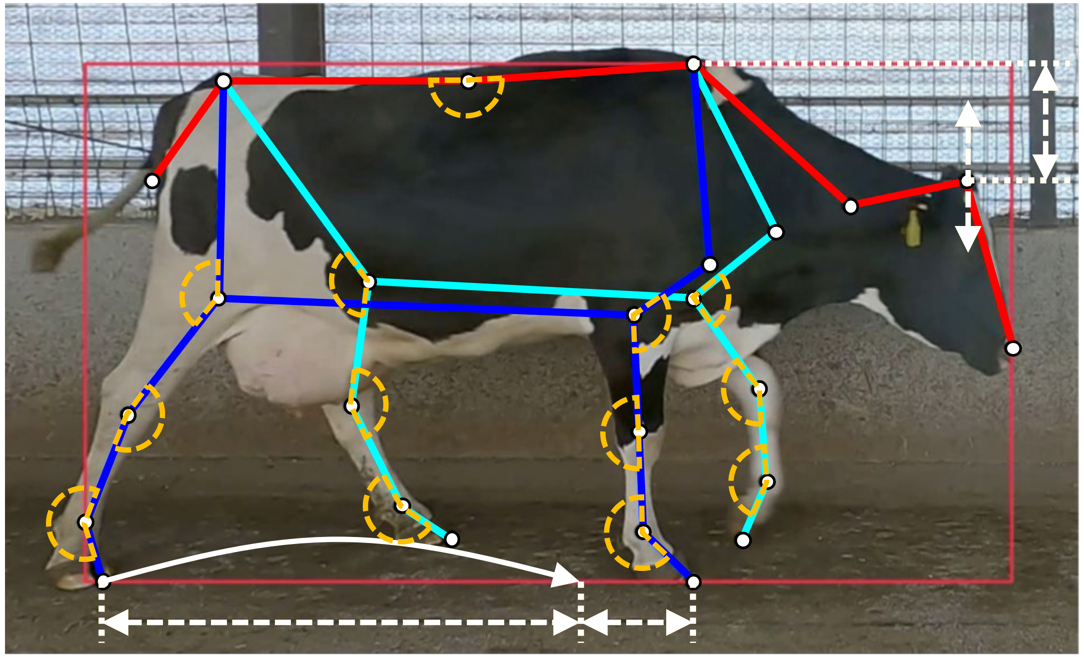
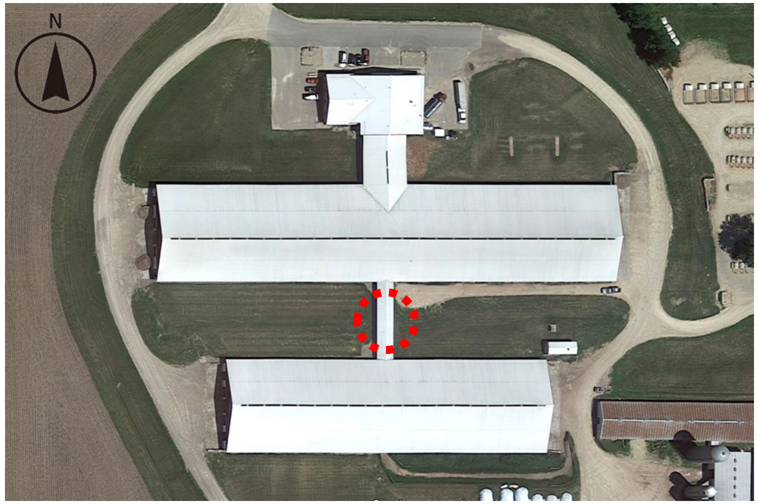


| Variables | Description |
|---|---|
| Head bob | Vertical movement of the head |
| Head position | Vertical distance between the heights of the head and the withers |
| Stride length (cm) | Horizontal distance between two consecutive toe landings of the same toe |
| Tracking-up (cm) | Horizontal distance between front toe landing and ipsilateral rear toe landing |
| Stride duration (s) | Time interval between two consecutive toe landings of the same toe |
| Stance duration (s) | Time interval between toe landing and following toe off |
| Swing duration (s) | Time interval between toe off and following toe landing |
| Stance phase (%) | Stance duration / stride duration |
| Swing phase (%) | Swing duration / stride duration |
| Walking speed (m/s) | Stride length / stride duration |
| Back angle (°) | Ventral angle at the back |
| Elbow joint angle (°) | Anterior angle at the elbow joint |
| Stifle joint angle (°) | Posterior angle at the stifle joint |
| Carpus joint angle (°) | Posterior angle at the carpus joint |
| Hock joint angle (°) | Anterior angle at the hock joint |
| Front fetlock joint angle (°) | Posterior angle at the front fetlock joint |
| Rear fetlock joint angle (°) | Posterior angle at the rear fetlock joint |

# Experiment overview


Video recording & selection
204 cows

Anotate mobility score

| | |
|---|---|
| Score 0 (Good): | 64 |
| Score 1 (Imperfect): | 65 |
| Score 2 (Impaired): | 57 |
| Score 3 (Severe): | 18 |

Pose estimation
Time series XY-coordinate data

Quantitative mobility analysis
10 spatial and temporal variables
7 joint angle related variables

Objective mobility scoring
Machine learning (Random Forest)

Training dataset
(80%)

Test dataset
(20%)

Classification model
(Score 0, 1, and 2+3)

Cross validation
(Repeated 10 times)

Performance evaluation
(Sen, Spe, PPV, NPV, Acc, Wt. kappa, AUC-ROC)

# Performance of machine learning classification model

Based on the 10 repeated holdout validation sets

| Mobility score | Number of cattle | Sensitivity (%) | Specificity (%) | Pos Pred Value (%) | Neg Pred Value (%) | Accuracy (%) | Weighted kappa | AUC-ROC* |
|---|---|---|---|---|---|---|---|---|
| 0 | 64 | 76.3 (69.1 – 83.5) | 86.6 (84.4 – 88.9) | 72.4 (66.8 – 78.0) | 88.6 (84.3 – 92.8) | 83.4 (80.4 – 86.5) | 0.69 (0.62 – 0.76) | 0.86 (0.84 – 0.89) |
| 1 | 65 | 59.0 (48.0 – 70.0) | 82.6 (79.6 – 85.6) | 61.7 (57.2 – 66.2) | 80.9 (76.6 – 85.2) | 74.9 (72.3 – 77.5) | | |
| 2 + 3 | 75 | 76.8 (70.8 – 82.8) | 86.8 (82.7 – 91.0) | 76.4 (69.2 – 83.5) | 87.2 (83.4 – 90.9) | 83.2 (79.7 – 86.6) | | |

*Area Under the Receiver Operating Characteristic Curve

Higaki et al., 2024 – Computers and Electronics in Agriculture

# Examples of applications of AiPEC

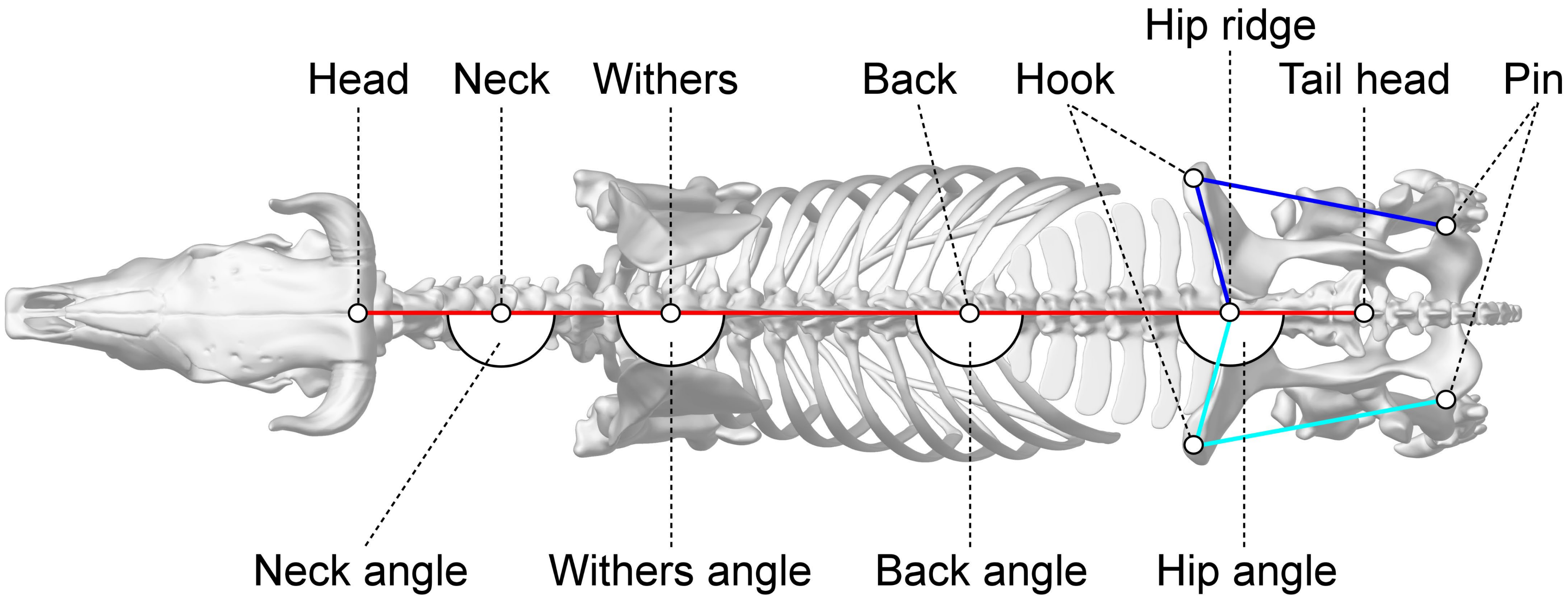
# Limitations of the present approach

Overlapping

Meandering

# New Strategy

# Top-down view keypoints

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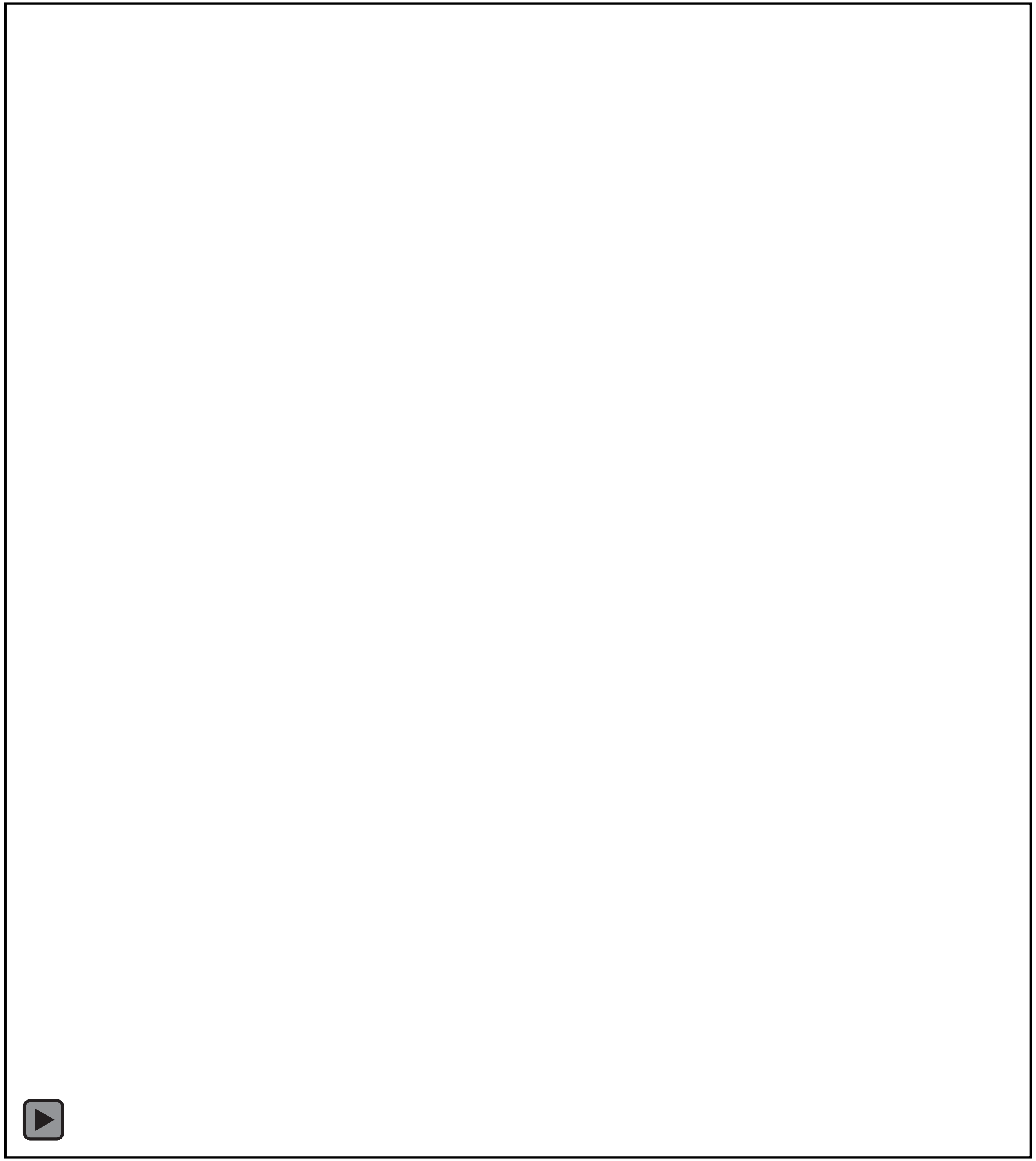

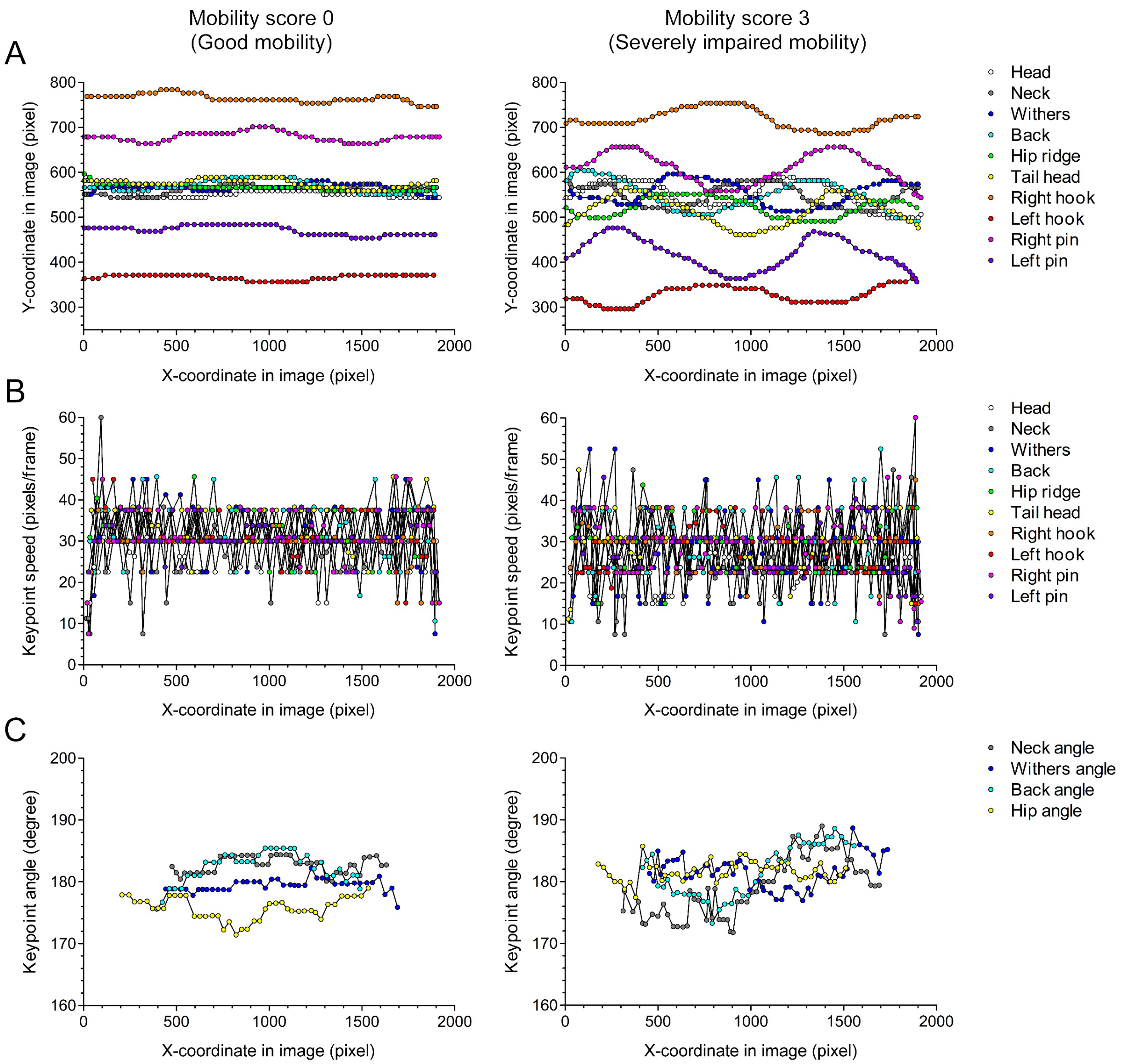


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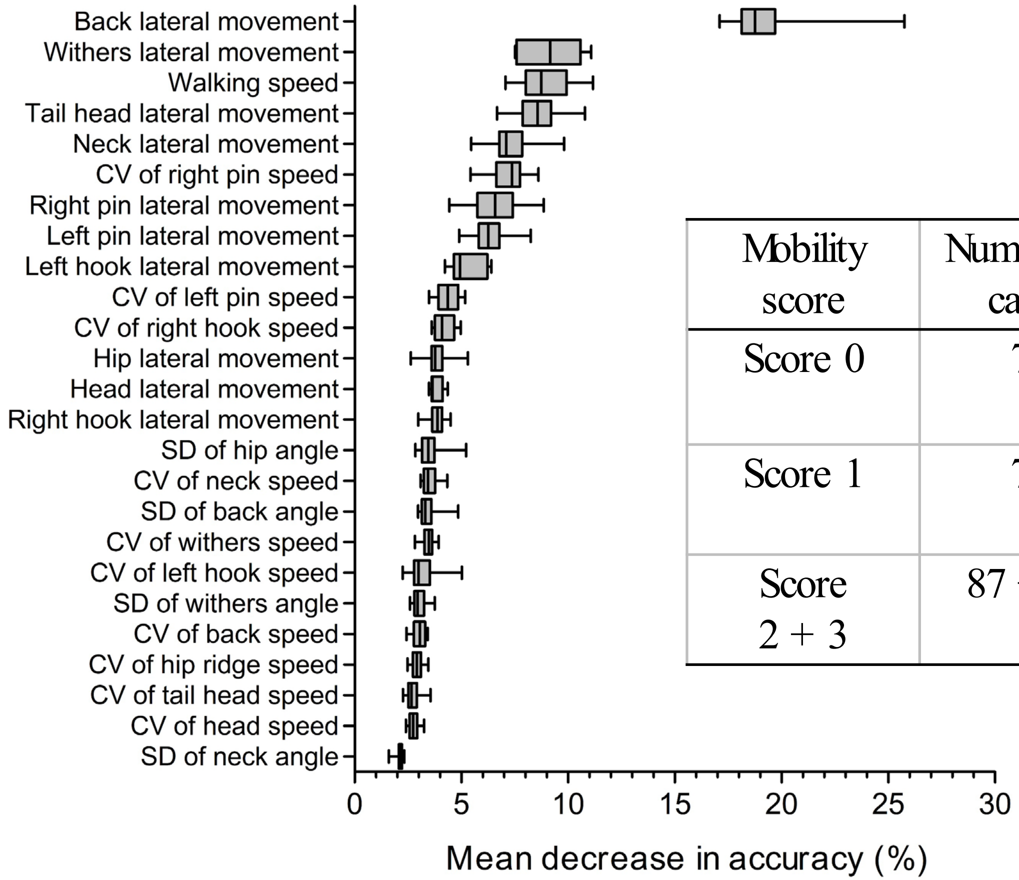
# Preliminary Results




| Mobility score | Number of cattle | Sensitivity (%) | Specificity (%) | F1-score (%) | Accuracy (%) | AUC-ROC[1] |
|---|---|---|---|---|---|---|
| Score 0 | 78 | 87.2 (80.7 – 93.7) | 94.7 (92.0 – 97.5) | 88.2 (83.8 – 92.5) | 92.1 (89.1 – 95.1) | 0.888 (0.866 – 0.910) |
| Score 1 | 71 | 54.4 (43.1 – 65.6) | 84.2 (79.5 – 88.8) | 55.4 (45.5 – 65.2) | 76.0 (71.1 – 80.8) | |
| Score 2 + 3 | 87 + 20 | 81.6 (74.9 – 88.2) | 82.3 (73.5 – 91.1) | 79.1 (74.8 – 83.5) | 82.3 (77.3 – 87.3) | |

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# Final Considerations

- Digital technologies are crucial to collect cheaper, precise, and real-time phenotypes
- Animal-level information is a very important component of any integrated databases
- Digital Agriculture: undergrad and grad courses (livestock, crop, water, soil - data management, storage, and analyses – cloud computing)
- New generation of students/professionals
- Multidisciplinary teams

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