The XX CIGR World Congress 2024

Behavioral Assessment in Dairy Calves Using Video-based Deep Learning Approach

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- Data Collection
- Behavior Recognition
- Behavioral Sequence Smoothing
- Behavioral Analysis

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Introduction | Background

“Behavioral assessment is crucial for assessing and ensuring the well-being of dairy cattle”

- Human observation: labor-intensive, experience, stress
- Sensor-equipped wearable devices: precise, invasive, limited to adult cattle
- Image-based monitoring: non-invasive, suitable for large-scale livestock farming

Introduction | Background

“It is particularly important to pay close attention on the behaviors of the vulnerable, newborn dairy calves”

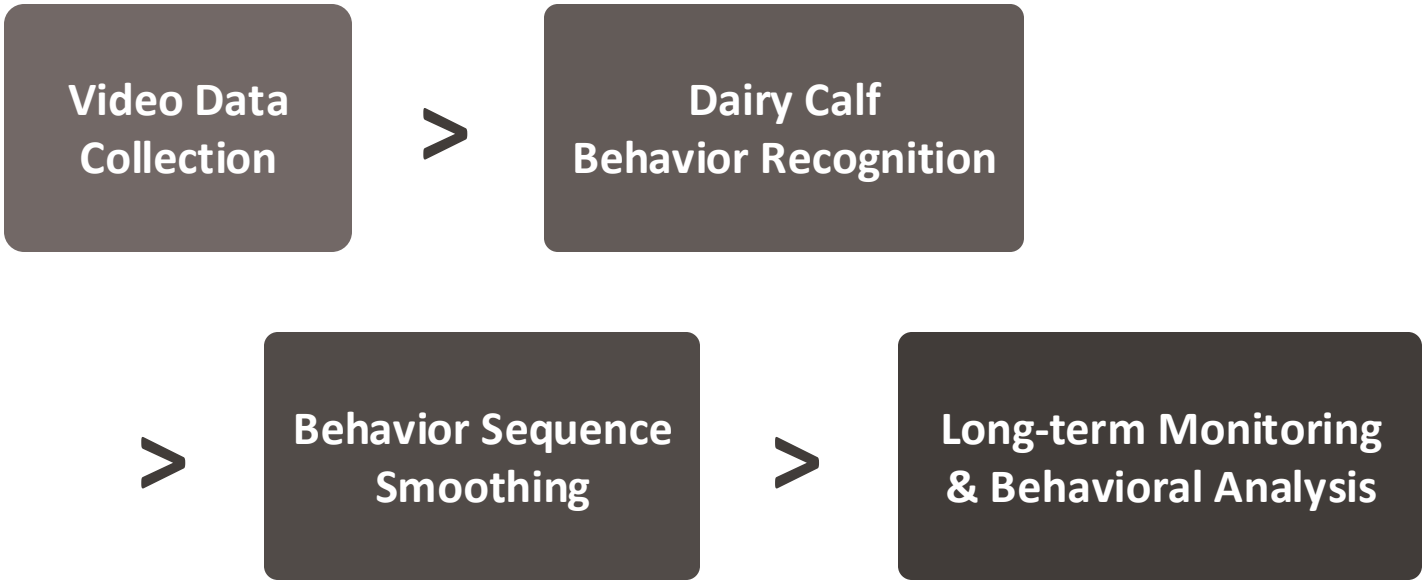
- susceptible to Neonatal Calf Diarrhea (NCD), which accounts for 75% of the losses within their first month
- adjusting calves’ diet is essential for digestive and ruminal health
- commercially-used wearable sensing devices are not suitable for newborn dairy calve

Introduction | Objectives

“To develop a video-based deep learning approach for behavioral assessment in dairy calves”

1. Behavior monitoring system for collecting video data on dairy calves
2. Deep learning model for behavioral recognition
3. Behavioral sequence smoothing for optimizing model predictions
4. Behavioral analysis and indicators for Neonatal Calf Diarrhea (NCD)

Materials & Methods | Overview



Materials & Methods | Data Collection

Monitoring Device

- Location: NTU's Experimental Dairy Farm
- Embedded System: Raspberry Pi 4
- Camera: Logitech C270 (1080x720 at 10FPS)
- Communication: SFTP, ZeroMQ through WiFi

Materials & Methods | Data Collection

Dairy Calf Behaviors

Nonactive Lying (NL)

Active Lying (AL)

Nonactive Standing (NS)

Active Standing (AS)

Ruminating (RM)

Feed Intake (FE)

Fluid Intake (FL)

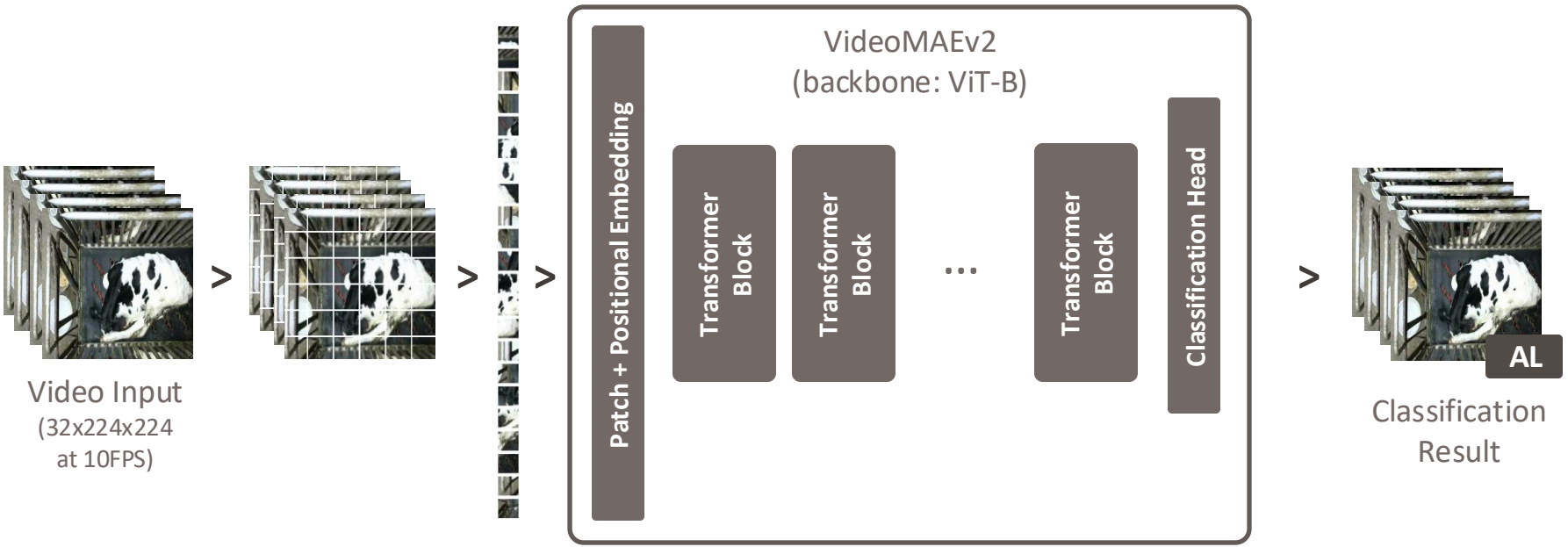
Materials & Methods | Data Collection

Behavior Datasets

	Nonactive Lying (NL)	Active Lying (AL)	Nonactive Standing (NS)	Active Standing (AS)	Rumination (RM)	Feed Intake (FE)	Fluid Intake (FL)	Total
Training & Validation (N=4397, I=16, D=92)	647	579	450	794	709	653	565	4397
Daily Assessment (N=17718, I=4, D=13)	9102	2345	199	3369	1910	500	293	17718

Materials & Methods | Behavior Recognition

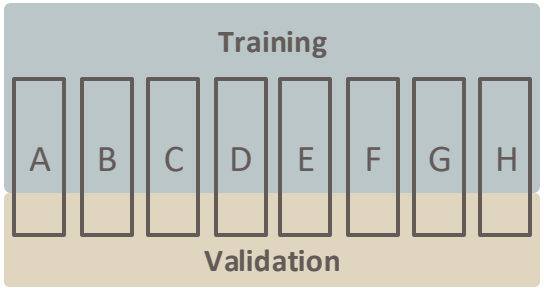
Video-based Behavior Recognition Model



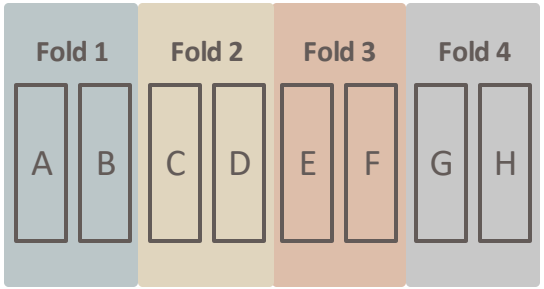
Materials & Methods | Behavior Recognition

Model Validation Strategies

- Random Split Validation



- Group K-Fold Cross-Validation



- Daily Behavioral Counting and Behavioral Distribution

Materials & Methods | Smoothing

Behavioral Sequence Smoothing

- Behavioral states in a temporal sequence are **interdependent**

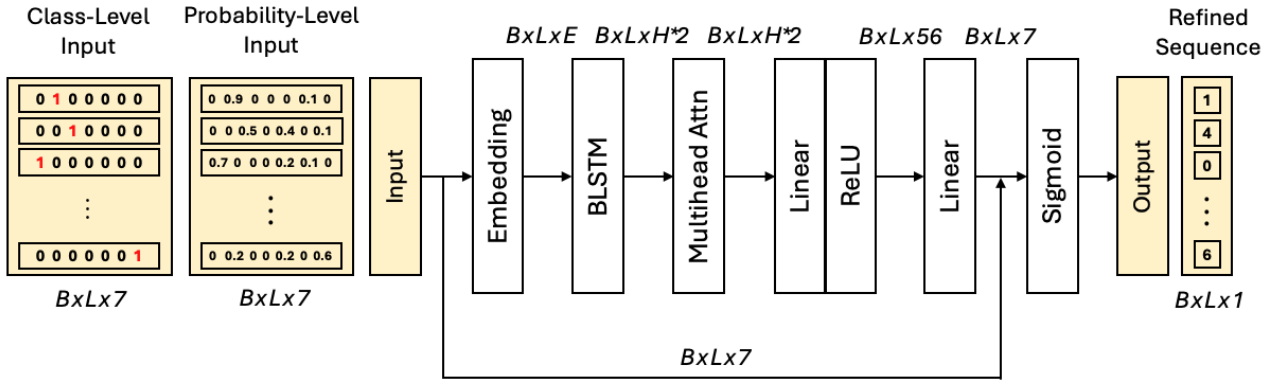
- Class-Level Smoothing (Predicted Labels)

- Probability-Level Smoothing (Predicted Probability Distribution)

- Feature-Level Smoothing (Intermediate Features in Behavior Recognition Model)

Materials & Methods | Sequence Smoothing

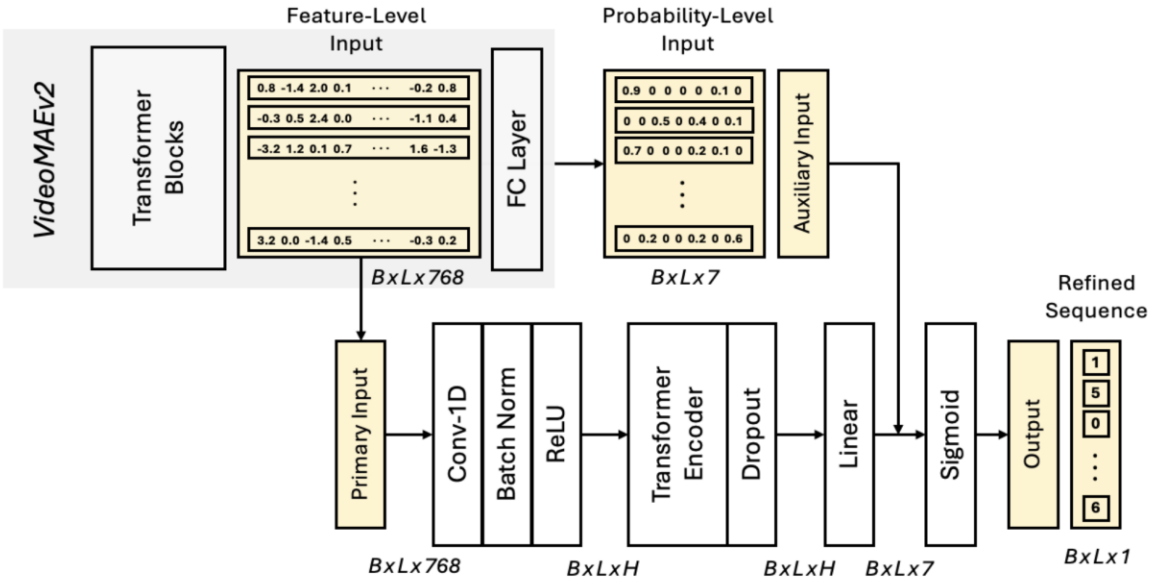
Class-Level & Probability-Level



B: batch size
L: sequence length
E: embedding dimension
H: hidden layers

Materials & Methods | Sequence Smoothing

Feature-Level



Materials & Methods | Sequence Smoothing

Performance Analysis

$$\text{Negative Log Likelihood Loss} = -\frac{1}{N}\sum_{i=1}^{N} \log\left(p_{i,y_i}\right)$$

$$\text{Weighted Cross Entropy Loss} = -\frac{1}{N}\sum_{i=1}^{N} w_{y_i} \cdot \log\left(p_{i,y_i}\right)$$

Materials & Methods | Behavioral Analysis

Behavioral Sampling and Statistical Analysis

- Daily statistical data including occurrence, bouts, average duration per bout of each behavior

Principal Component Analysis (PCA)

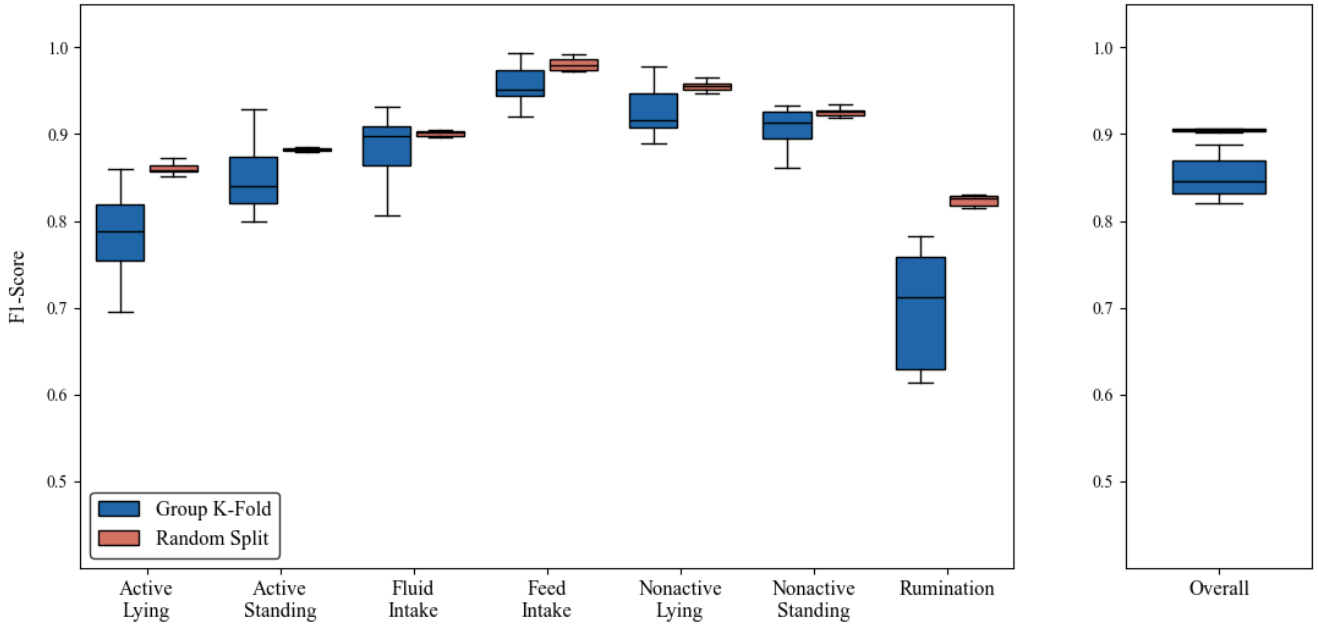
- Visualization of the behavioral differences in dairy calves

Feature Importance for Neonatal Calf Diarrhea (NCD)

- Identification of key behavioral features associated with NCD

Result | Behavior Recognition Model

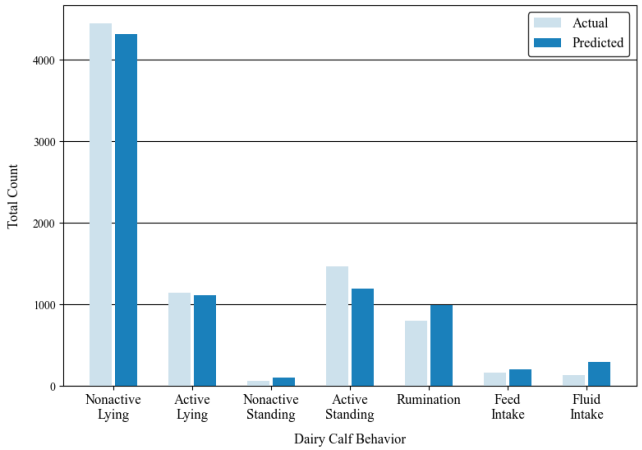
Random Split & Group K-Fold Validation



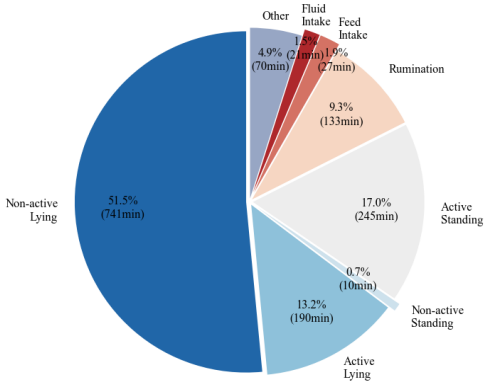
	Macro-F1
Fold-1	0.827
Fold-2	0.889
Fold-3	0.846
Fold-4	0.820
Fold-5	0.845
Fold-6	0.878
Fold-avg	**0.850**
Random Split	**0.907**

Result | Behavior Recognition Model

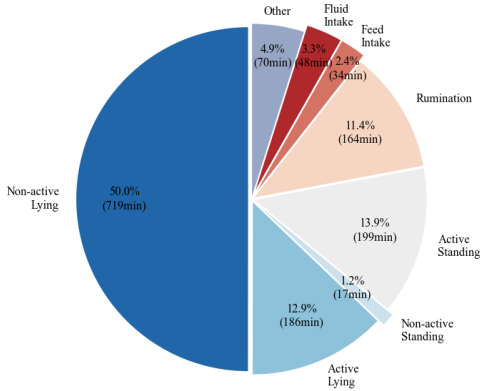
Daily Behavioral Counting



Daily Behavioral Distribution



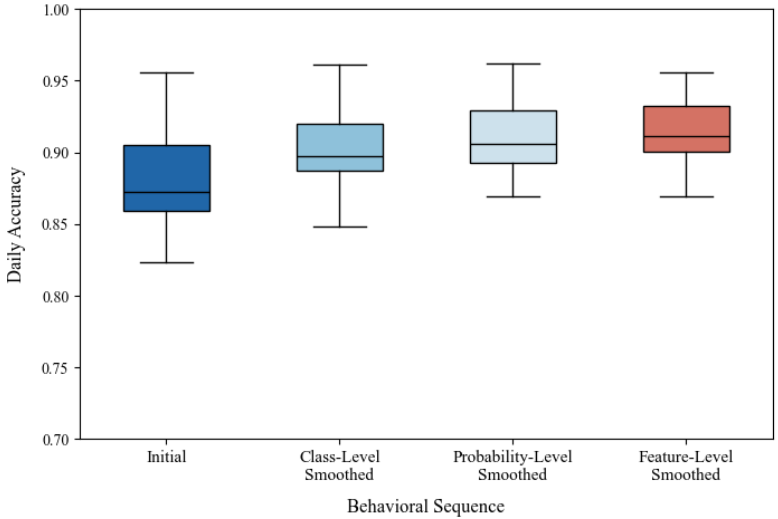
Actual



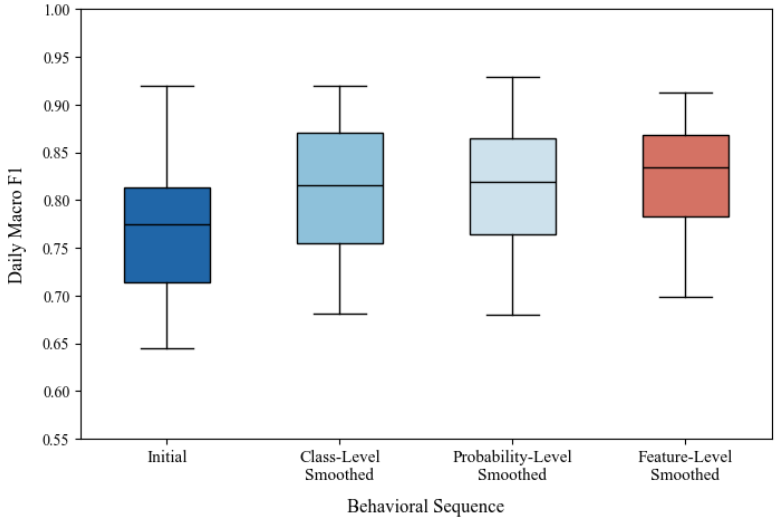
Predicted

Result | Behavior Sequence Smoothing

Smoothing Performance



Daily Accuracy



Daily Macro F1-Score

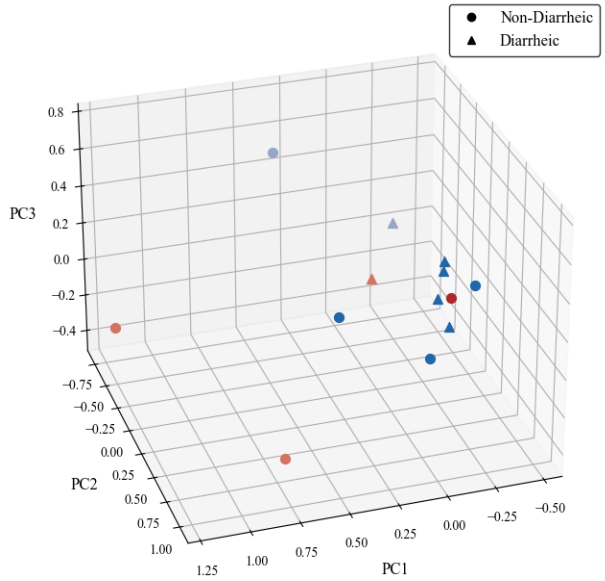
Result | Behavioral Analysis

Daily Behavioral Statistics in Dairy Calves

	Daily Occurrence (min/d)		Daily Bout Counts (bout/d)		Average Bout Duration (min/bout)	
Behavior	**Mean (μ)**	**SD (σ)**	**Mean (μ)**	**SD (σ)**	**Mean (μ)**	**SD (σ)**
Nonactive Lying (NL)	700.2	87.9	100.6	17.9	7.15	1.45
Active Lying (AL)	180.4	40.4	99.6	21.9	1.81	0.21
Nonactive Standing (NS)	15.3	12.8	12.1	8.0	1.20	0.16
Active Standing (AS)	259.2	59.3	78.5	13.4	3.35	0.80
Rumination (RM)	147.8	85.1	62.5	13.8	2.49	1.62
Feed Intake (FE)	38.5	22.4	28.2	11.6	1.31	0.25
Fluid Intake (FL)	22.5	11.9	18.3	8.5	1.21	0.14

Result | Behavioral Analysis

Principal Component Analysis



- Each point represents a day

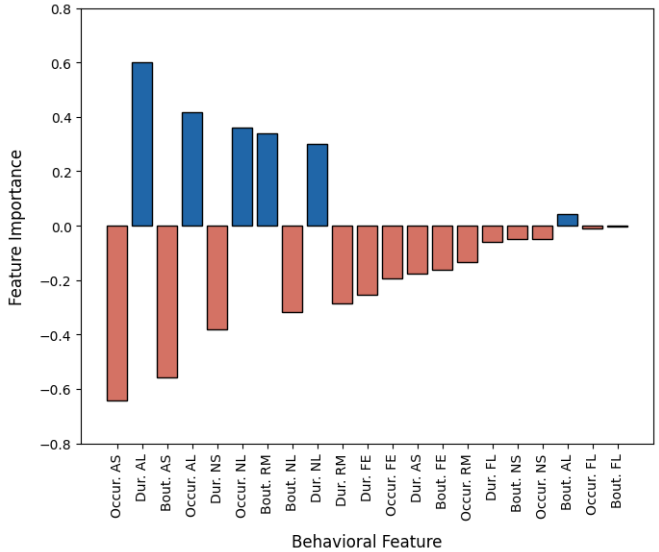
- Each color represents data from a dairy calf individual

- Non-diarrheic and Diarrheic data are marked in different signs

- Regardless of the individual, instances of scours are characterized by diminished values on PC1, PC2, and PC3 axes

Result | Behavioral Analysis

Feature Importance for Neonatal Calf Diarrhea (NCD)



- Positive values indicate a positive relationship with NCD

- A decrease in daily occurrence of Active Standing is a strong indicator of NCD

- An increase in bout duration of Active Lying is positively correlated with NCD

Conclusion

1. A behavior monitoring system was developed to collect video data at the NTU's experimental dairy farm.
2. The video-based behavior recognition model was evaluated through Random Split Validation and Group K-Fold Validation, achieving F1-scores of **0.91** and **0.85,** respectively.
3. The behavior sequence smoothing at three levels: Class-Level, Probability- Level, and Feature-Level effectively enhanced the daily accuracy and macro F1-score.
4. The statistical analysis and principal component analysis revealed behavioral tendencies in dairy calves.
5. The calculated feature importance identified key behavioral indicators of **Neonatal Calf Diarrhea (NCD),** including decreased occurrence of Active Standing and increased average bout duration of Active Lying.


Thank You For Listening