11th International Symposium on Machinery and Mechatronics for
Agriculture and Biosystems Engineering (ISMAB 2024)
27-29 Sep. 2024, Bali, Indonesia

An Efficient AIoT Framework for Image-Based Behavior Monitoring in Dairy Calves

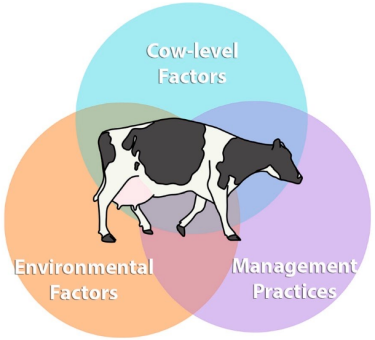
Po-Lin Chen, Rui-Yuan Liao, Jih-Tay Hsu, Ta-Te Lin

Department of Biomechatronics Engineering, National Taiwan University, Taipei, Taiwan

National Taiwan University Department of Biomechatronics Engineering Biophotonics & Bioimaging Laboratory

Introduction

Introduction | Importance of behavior monitoring in dairy calves



Health Issues > **Detection** > **Treatment**

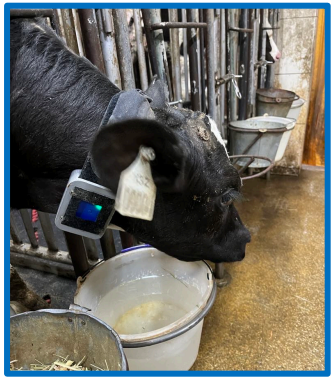
- Neonatal calf diarrhea
- Pneumonia

- Less active
- Feeding behavior

- Electrolytes, water, antibiotics
- Diet adjustments

Introduction | Automatic behavior monitoring systems

- **Wearable Sensors**
  - Precise measurements
  - Limited used for newborn dairy calves



- **Image-based Monitoring**
  - Non-contact, Low-cost
  - Suitable for large-scale monitoring

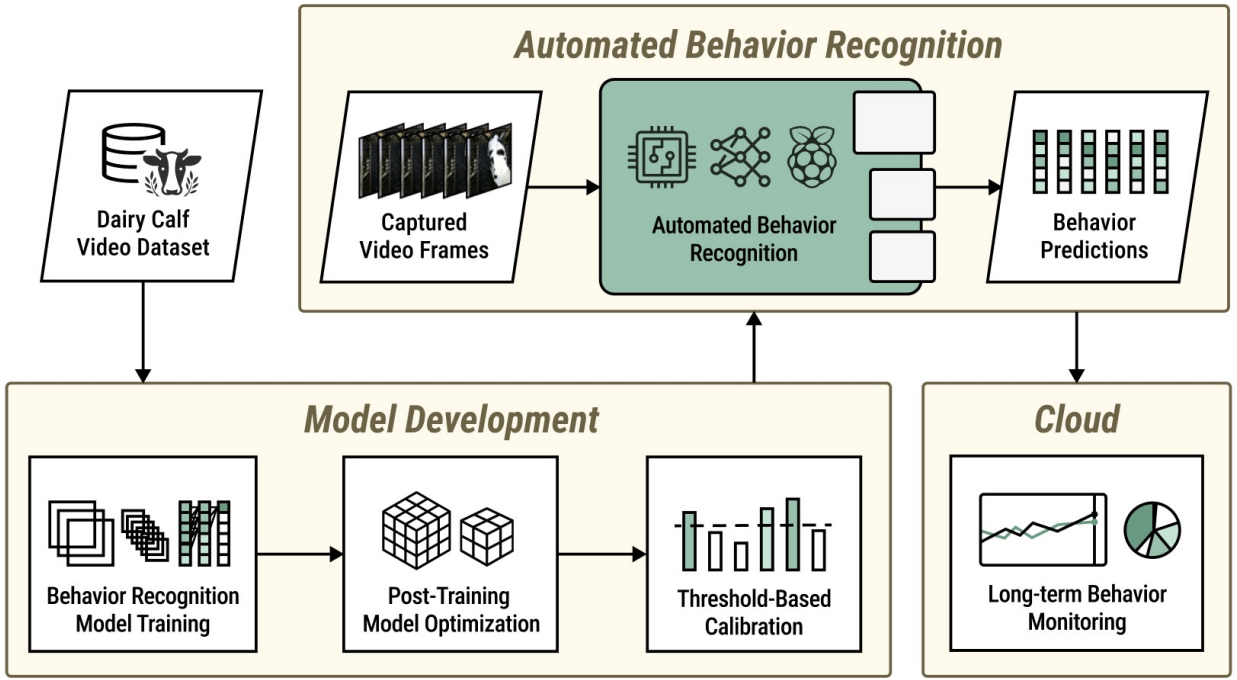
Introduction | Objectives

- **To develop an efficient AIoT framework for image-based behavior monitoring for dairy calves**

1. An imaging system for continuous monitoring and edge computing
2. Deep learning models for video-based behavior recognition
3. Post-training model optimization for computation-efficient edge computing
4. Long-term experiments to demonstrate our system's effectiveness in real-world farming environments

Materials and Methods

Materials & Methods | System Overview



Materials & Methods | Dairy Calf Behavioral Video Dataset

Nonactive Lying
(647)

Active Lying
(579)

Nonactive Standing
(450)

Active Standing
(794)

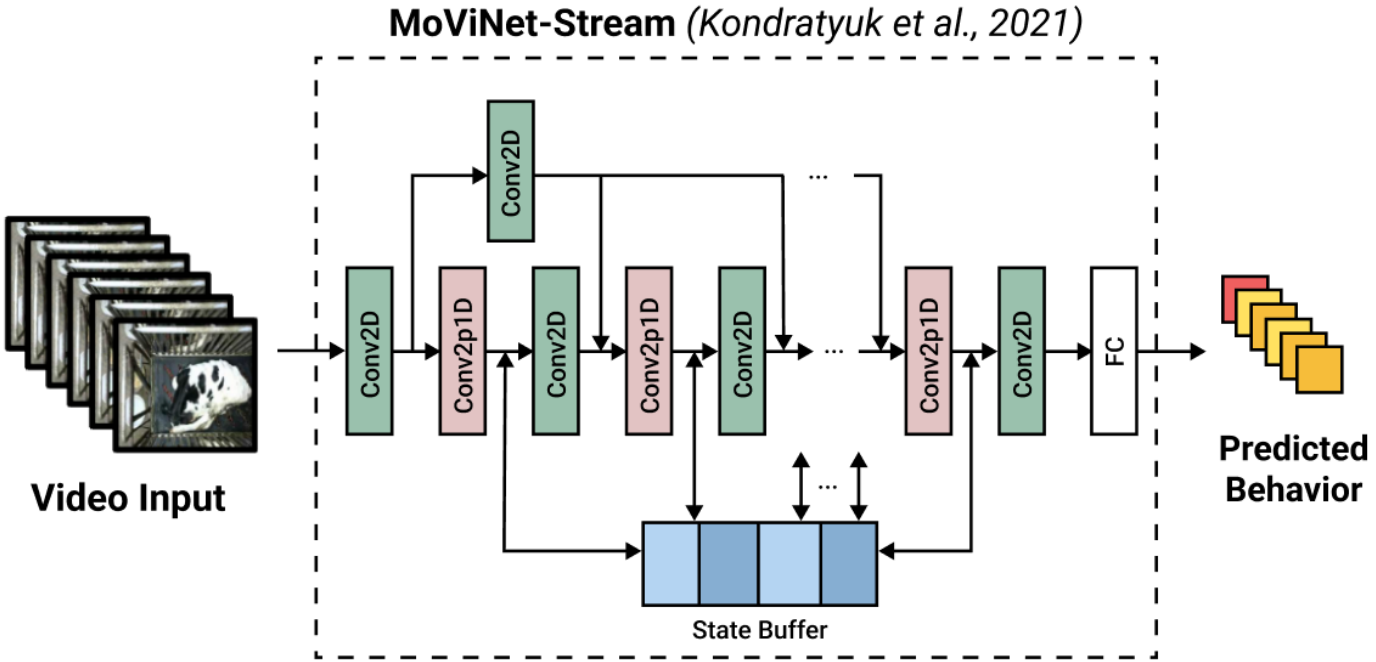
Drinking
(565)

Feeding
(653)

Ruminating
(709)

Duration	3.2 sec
Frames	32
FPS	10
Resolution	224 x 224
Channels	RGB
Location	NTU's Experimental Dairy Farm

Materials & Methods | Dairy Calf Behavior Recognition Model



Materials & Methods | Performance Analysis

- **Predictive Performance**

  - Average F1-score

- **Hardware Performance**

  - Latency

  - Peak Memory Usage

Raspberry Pi 4 Model B

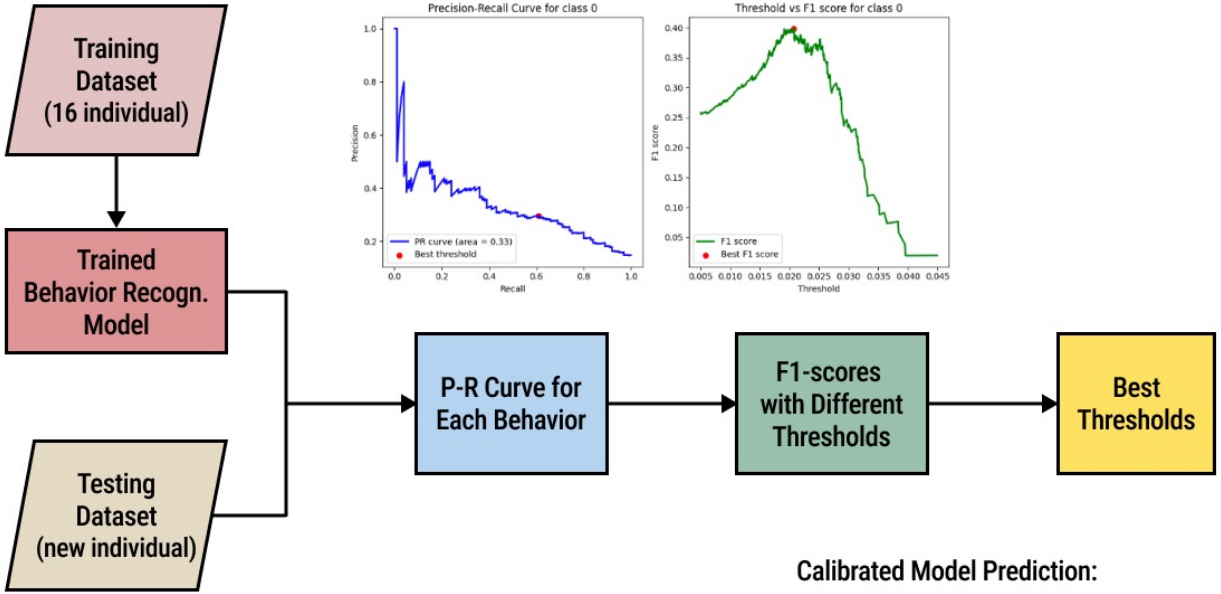
- **Processor:** Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz
- **RAM:** 4GB LPDDR4-3200 SDRAM

Materials & Methods | Post-Training Model Optimization

- **Post-Training Quantization** for **reduced computational demand** and **enhanced inference speed** on the edge devices

Quantization	Input	Weights	Output	Size	Description
No Quantization (Float32)	float32	float32	float32	1	Without quantization
Post-training Float16 Quantization	float32	**float16**	float32	1/2	Weights are stored in float16
Post-training Int8 Quantization (float fallback)	float32	**int8**	float32	1/4	Calculated in int8, but falls back to float if needed

Materials & Methods | Threshold-Based Calibration

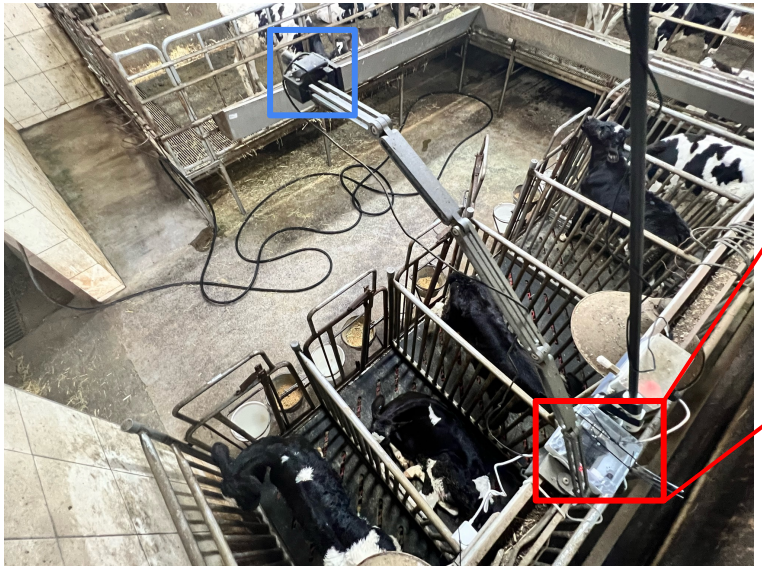


Calibrated Model Prediction:

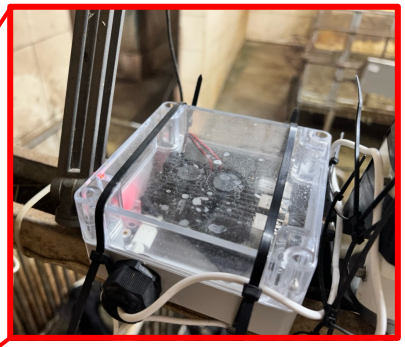
$$\hat{B} = \begin{cases} \arg\max_{i \in \{1,2,\ldots,7\}} P(B_i), & \text{if } P(B_i) > T_i \text{ for some } i \\ \text{null}, & \text{if } P(B_i) \leq T_i \text{ for all } i \end{cases}$$

Materials & Methods | Long-term Behavior Monitoring

camera



embedded system



- **Location:** NTU's Experimental Dairy Farm
- **Embedded System:** Raspberry Pi
- **Subject:** A newborn Holstein calf
- **Duration:** 18 days

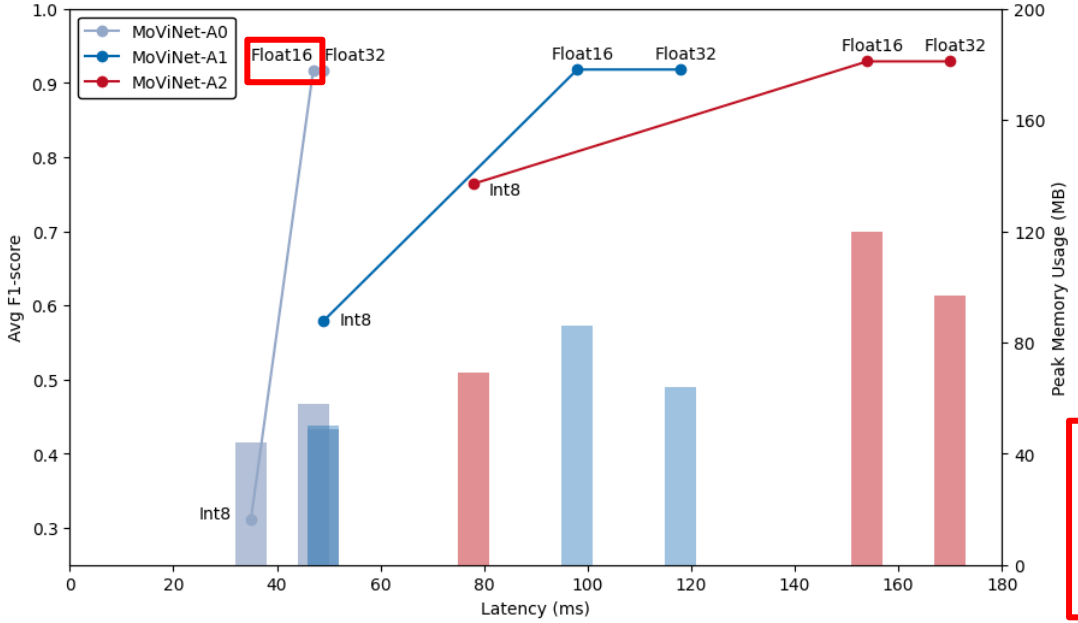
Results and Discussions

Results & Discussions | Behavior Recognition Model Performance

- **Model:** MoViNet-A0, MoViNet-A1, MoViNet-A2
- **Quantization:** Float32 (No Quantization), Float16 Quantization, Int8 Quantization

Model	Quantization	Latency (ms)	Peak Memory Usage (MB)	Average F_1-score
MoViNet-A0	Float32*	49	49	0.916
	Float16	47	58	0.916
	Int8	35	44	0.312
MoViNet-A1	Float32*	118	64	0.918
	Float16	98	86	0.918
	Int8	49	50	0.579
MoViNet-A2	Float32*	170	97	0.929
	Float16	154	120	0.929
	Int8	78	69	0.764

Results & Discussions | Behavior Recognition Model Performance



- **Avg F1-score**
  - Float16, Float32
- **Latency**
  - No more than 100ms (at 10FPS)
- **Peak Memory Usage**
  - All applicable on Raspberry Pi

Best Choice:

MoViNet-A0 with Float16 Quantization

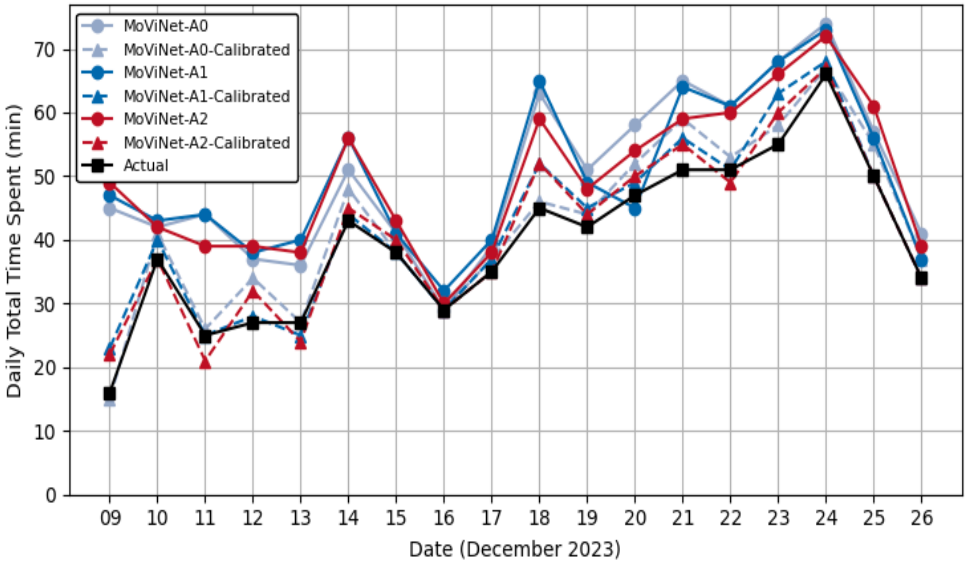
(F1: **0.916**, Latency: **47ms**, Memory: **49MB**)

Results & Discussions | Long-term Dairy Calf Behavior Monitoring

- **Non-active Lying**
- **Active Lying**
- **Non-active Standing**
- **Active Standing**
- **Feeding**
- **Drinking**
- **Ruminating**

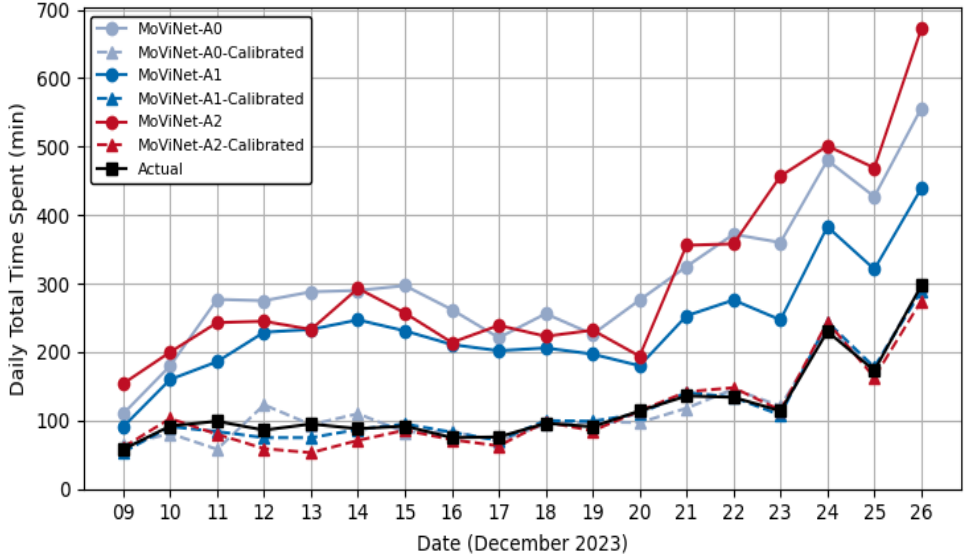
Results & Discussions | Long-term Dairy Calf Behavior Monitoring

- **Non-active Lying**
- **Active Lying**
- **Non-active Standing**
- **Active Standing**
- **Feeding**
- **Drinking**
- **Ruminating**

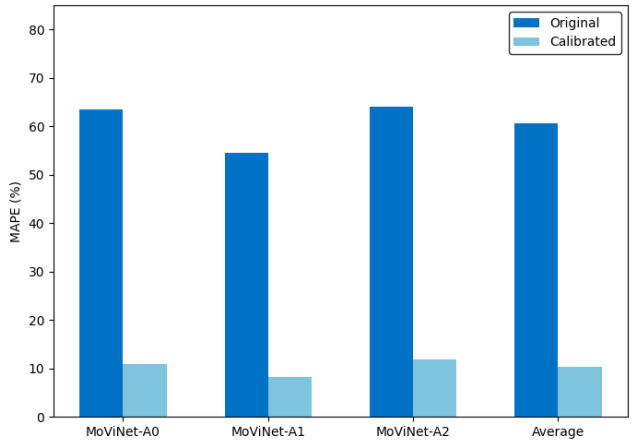


Results & Discussions | Long-term Dairy Calf Behavior Monitoring

- **Non-active Lying**
- **Active Lying**
- **Non-active Standing**
- **Active Standing**
- **Feeding**
- **Drinking**
- **Ruminating**

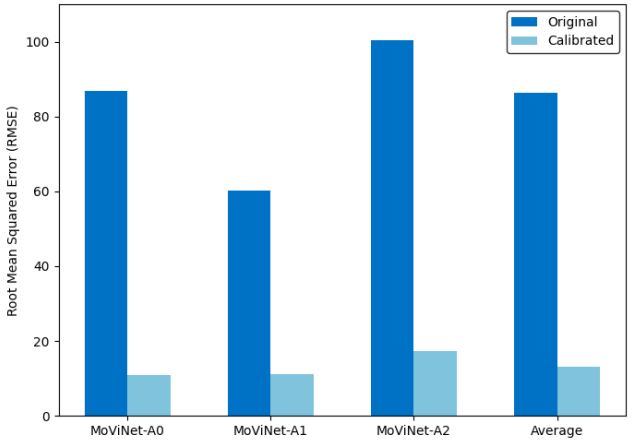


Results & Discussions | Long-term Dairy Calf Behavior Monitoring



Avg. MAPE after calibration: 10.4%

MoViNet-A0: 11.0%



Avg. RMSE after calibration: 13.1 m/d

MoViNet-A0: 10.8 m/d

Conclusion

Conclusion |

Dairy Calf Behavioral Video Dataset

- **4,000+** video clips were collected for training and validation, covering **7** distinct behaviors: Nonactive Lying, Active Lying, Nonactive Standing, Active Standing, Feeding, Drinking, and Ruminating.

Dairy Calf Behavior Recognition Model

- The predictive and hardware performance of various **MoViNet Architectures** (MoViNet-Stream-A0, A1, A2) with different **Post-training Quantization** (Float32, Float16, Int8) were compared.
- The **MoViNet-Stream-A0 model** with **Float16 Quantization**, with its low **latency** of **47ms** on **64-bit Raspberry Pi 4 Model B** and high **F1-score** of **0.916**, was identified as the most suitable for dairy calf behavior monitoring.

Conclusion |

Long-term Dairy Calf Behavior Monitoring

- An **18-day** behavior monitoring experiment on a Holstein calf was conducted to demonstrate our system's effectiveness at the National Taiwan University's Experimental Dairy Farm.
- After **Threshold-based Calibration,** the **MoViNet-Stream-A0 model** with **Float16 Quantization** model achieved a **11.0% MAPE** and a **10.8 min/day RSME**.

Thank you for your time