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EDGE-AI-BASED DAIRY CALF BEHAVIOR MONITORING SYSTEM USING COMPUTER VISION AND IOT TECHNOLOGIES

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ABSTRACT

We present an edge-AI, IoT system for real-time monitoring of dairy calf behavior that runs on embedded system and streams only compact results to the cloud. A lightweight, quantized MoViNet-A2 model deployed on a Raspberry Pi 4 classifies seven behaviors (non-active/active lying, non-active/active standing, feeding, drinking, ruminating) from 4-s clips captured once per minute, and publishes JSON outputs to AWS for dashboards. Field trials on three Holstein calves at the National Taiwan University experimental farm demonstrated continuous operation and minute-level freshness from barn to visualization. The model achieved an average F1-score of 0.919 with 128 ms per frame on Raspberry Pi, meeting accuracy and latency targets under tight compute and power budgets. Using the cloud dashboards, minute-level detections were converted into growth-linked KPIs, including a sigmoid decline in daily non-active lying with a clear inflection day (maturation marker), an active–non-active crossover around weaning (time-budget reallocation), and feeding–rumination coupling (rumen development indicator). The results show that an edge-AI pipeline can deliver accurate recognition and actionable analytics at low cost, providing a practical and scalable approach for intelligent dairy calf management.

Keywords: deep learning, edge computing, cloud services, real-time monitoring, behavioral analysis

INTRODUCTION

Scaling dairy production increases the need for real-time, low-cost monitoring of calf behaviors to support health, welfare, and management (Tangorra et al., 2024; Leliveld et al., 2024). Core behaviors - lying/rest, standing/activity, feeding, drinking, and rumination - are sensitive, non-invasive indicators of development and welfare status. While wearable sensors provide continuity, farm-scale use is constrained by battery replacement, device loss, and handling stress in youngstock. Server-side vision systems, meanwhile, incur latency, bandwidth, and privacy costs. We address these gaps with an edge-AI, IoT solution: a lightweight, quantized MoViNet-A2 runs on Raspberry Pi to recognize seven behaviors from short clips, then sends compact results to AWS for minute-level dashboards. Field deployment on three Holstein calves demonstrated continuous operation and enabled conversion of detections into interpretable, day-scale growth indicators.

MATERIALS AND METHODS

We deployed the system on three Holstein calves from birth through the weaning transition (~2 months) at the NTU experimental dairy farm. A Raspberry Pi 4 with a Logitech C270 camera (≈720p, 10 fps) captured a 4-s clip once per minute and performed on-device inference using a lightweight, quantized MoViNet-A2 (TFLite INT8, 224×224) to classify seven behaviors (non-active/active lying, non-active/active standing, feeding, drinking, ruminating). After each inference, the device sent a compact JSON result identifying the detected behavior (non-active/active lying, non-active/active standing, feeding, drinking, or ruminating) to AWS, where the data were stored and displayed in near real time; no raw video was transmitted. Evaluation used hand-labeled clips, reporting F1-score (average and per class), confusion patterns, per-frame latency and memory use on the Pi, and edge-to-dashboard freshness.

RESULTS & DISCUSSION

The system ran continuously on-farm with minute-level freshness from edge to dashboard. The quantized MoViNet-A2 achieved an average F1-score of 0.919 with 128 ms per frame and a modest memory footprint on Raspberry Pi, meeting accuracy and latency targets under tight compute limits. A lightweight temporal denoising step reduced one-minute label flips, yielding steadier daily time budgets and bout statistics without altering trends.

From the dashboards, minute-level outputs were converted into growth-linked KPIs. Daily non-active lying followed a sigmoid decline from an early high plateau to a lower late plateau; the inflection day serves as a compact maturation marker. The active vs. non-active curves exhibited a consistent crossover around weaning, indicating reallocation of the time budget from rest to activity. Finally, feeding and rumination rose together, supporting their use as indicators of rumen development. Together, these findings show that an edge-AI pipeline can deliver accurate recognition, stable day-scale analytics, and actionable KPIs suitable for routine farm management.

CONCLUSIONS

We built an edge-AI, IoT system that recognizes seven calf behaviors on-device and posts compact results to AWS dashboards. On-farm, the quantized MoViNet-A2 ran continuously within compute limits, and its minute-level outputs yielded growth-linked KPIs - rest sigmoid with inflection, active–non-active crossover near weaning, and feeding–rumination coupling - to support routine management. This work highlights the innovative integration of lightweight deep learning with edge computing for livestock, reducing bandwidth while enabling scalable on-farm deployment. The system further demonstrated long-term monitoring, providing consistent behavioral insights to support precision calf management. Next steps include multi-farm validation and refining rumination with slightly longer temporal context.

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