

# Mitigating Heat Stress in Dairy Cattle using a Physiological Sensing-Behavior Analysis-Microclimate Control Loop

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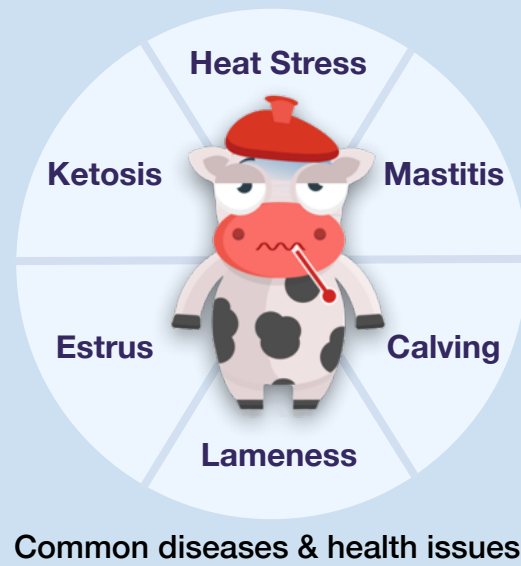


## MOTIVATION

Precision livestock farming enhances productivity, animal welfare, and environmental sustainability

Multimodal and synchronized datasets are necessary for more accurate and efficient machine learning models

There is a lack of synchronized multimodal datasets for precision livestock farming



## DATA COLLECTION

### Nine synchronized modalities of MmCows



### The sensor suite

#### 1. Custom neck-mount tag:

- An ultra-wideband module (UWB) that keeps track of the location
- An inertia and magnetic measurement unit (IMMU) for measuring the head direction
- A pressure sensor that measures the elevation of the cow's neck

#### 2. Ankle sensor:

- An accelerometer attached to the cow's leg to record its lying behavior

#### 3. Vaginal temperature sensor:

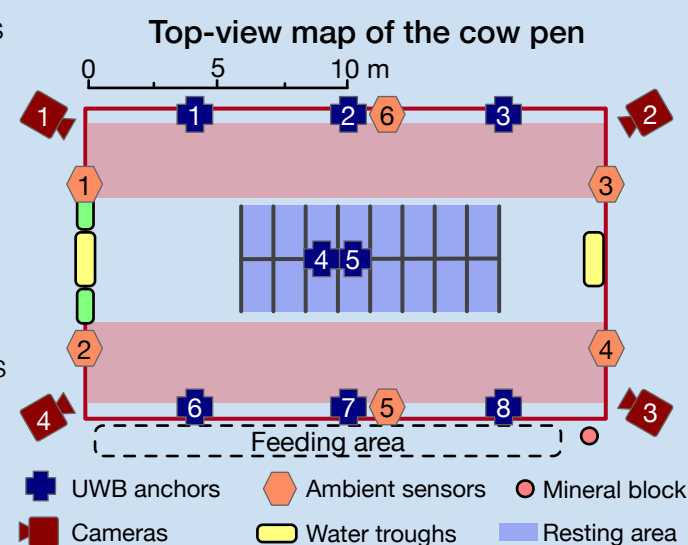
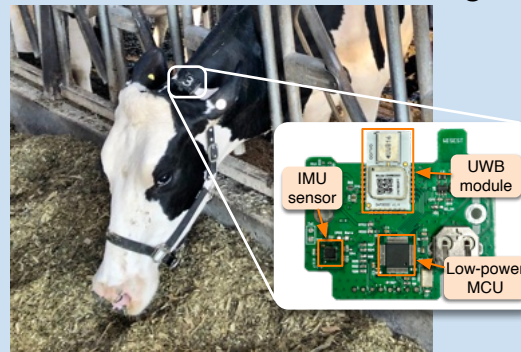
- A temperature sensor to measure the core body temperature

#### 4. Other sensors:

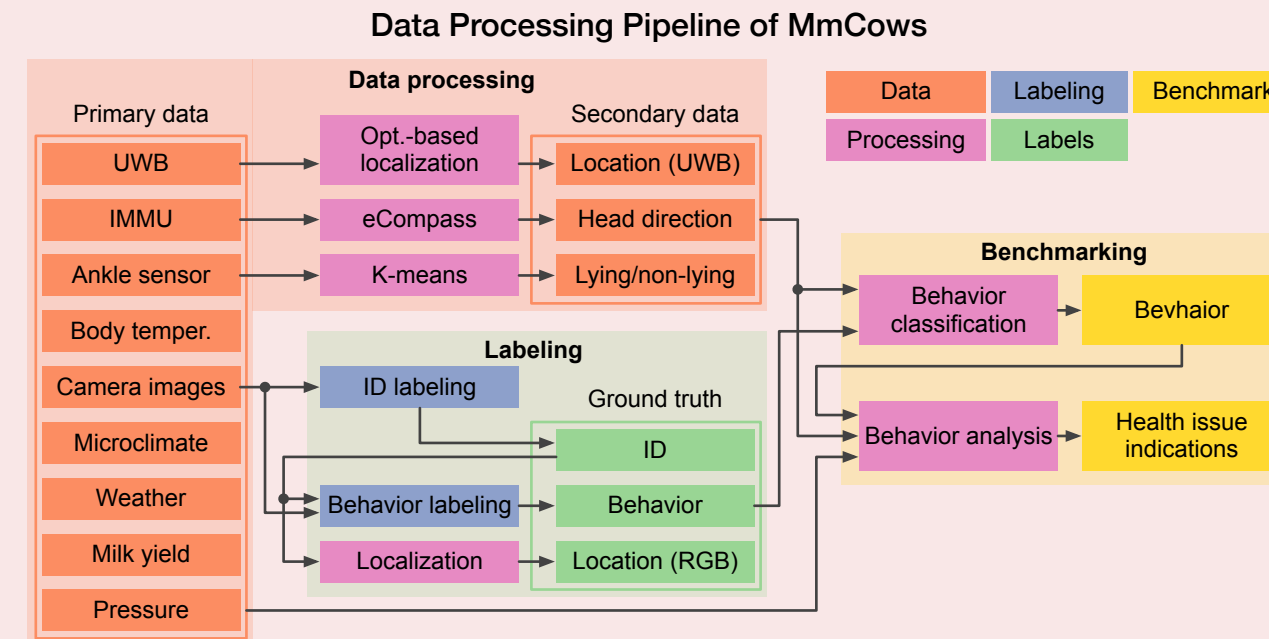
- Isometric-view cameras, microclimate sensors, outdoor weathers, and records

The sensor suite were deployed during 14 days at UW-Madison's Arlington Agricultural Research Station

### Custom wearable neck-mount tag



## DATA PROCESSING



### Data processing:

- Extracting meaningful data: 3D neck location, 3D head direction, and lying behavior

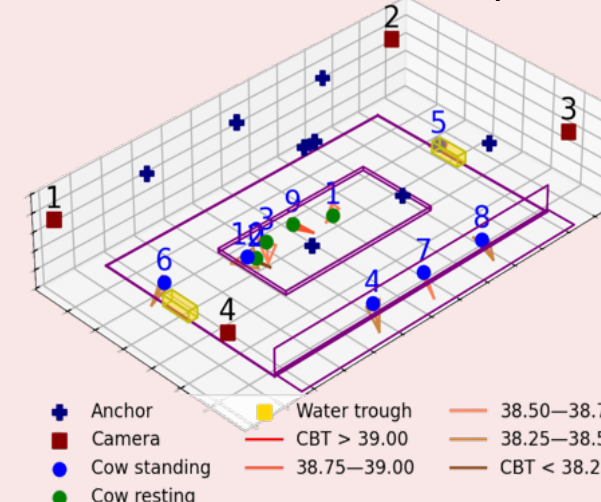
### Cow identification ground truth (gt):

- Annotated 20,000 images from July 25th with 213,000 bounding boxes of 16 cows
- Utilized to derive 3D body location gt

### Behavior ground truth:

- Fine-grained interval of walking, standing, feeding head up, feeding head up/down, drinking, licking, and lying behaviors

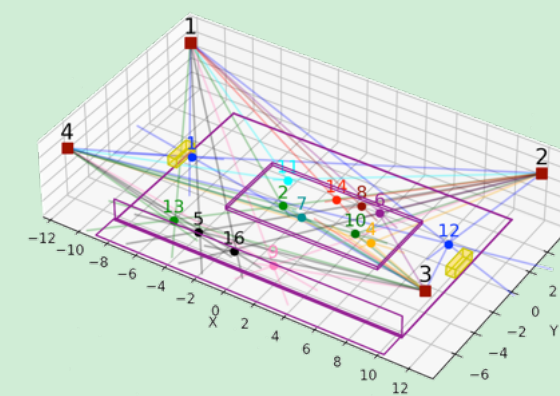
### Visualization of multiple modalities in 3D view of the pen



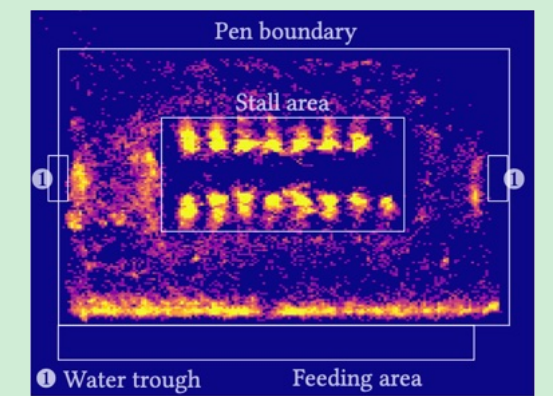
### Cow ID annotations and UWB locations in multi-view images



### Visual localization for multiple cows



### Heat map of visual location ground truth



## BENCHMARKS

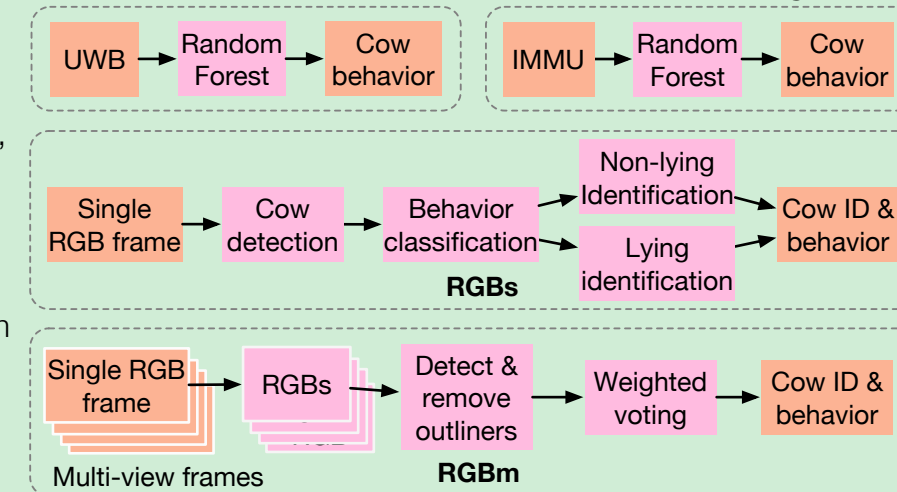
### Behavior monitoring using single modality and their combinations:

- Single modality: UWB, IMMU, RGBs
- Combinations: UWB+HD, UWB+HD+AKI, RGBm

### Split settings:

- Temporal split (TS) & object-wise split (OS)

### Multimodal cow identification and behavior recognition



### Performance comparison of behavior classification using different modalities

Modality	Set- ting	F1 score $\uparrow$							
		Walking	Standing	Feeding $\uparrow$	Feeding $\downarrow$	Licking	Drinking	Lying	Average
UWB	OS	.078 $\pm$ .027	.855 $\pm$ .023	.704 $\pm$ .077	.834 $\pm$ .049	.884 $\pm$ .054	.644 $\pm$ .112	.953 $\pm$ .017	.707 $\pm$ .051
	TS	.103 $\pm$ .040	.860 $\pm$ .041	.738 $\pm$ .026	.835 $\pm$ .029	.868 $\pm$ .066	.656 $\pm$ .059	.961 $\pm$ .008	.717 $\pm$ .038
IMMU	OS	.000 $\pm$ .000	.065 $\pm$ .127	.067 $\pm$ .084	.098 $\pm$ .135	.000 $\pm$ .000	.000 $\pm$ .000	.700 $\pm$ .760	.133 $\pm$ .060
	TS	.000 $\pm$ .000	.052 $\pm$ .053	.000 $\pm$ .000	.051 $\pm$ .048	.000 $\pm$ .000	.000 $\pm$ .000	.742 $\pm$ .126	.141 $\pm$ .038
RGBs	TS	.143 $\pm$ .036	.814 $\pm$ .048	.634 $\pm$ .063	.715 $\pm$ .051	.484 $\pm$ .193	.409 $\pm$ .116	.681 $\pm$ .032	.554 $\pm$ .077
UWB+HD	OS	.032 $\pm$ .030	.908 $\pm$ .015	.731 $\pm$ .059	.843 $\pm$ .046	.812 $\pm$ .154	.645 $\pm$ .136	.980 $\pm$ .006	.707 $\pm$ .064
	TS	.074 $\pm$ .036	.917 $\pm$ .022	.766 $\pm$ .030	.853 $\pm$ .026	.863 $\pm$ .057	.699 $\pm$ .049	.986 $\pm$ .003	.737 $\pm$ .032
UWB+HD+AKI	OS	.048 $\pm$ .040	.937 $\pm$ .014	.730 $\pm$ .057	.842 $\pm$ .044	.800 $\pm$ .183	.643 $\pm$ .132	.996 $\pm$ .001	.714 $\pm$ .067
	TS	.055 $\pm$ .026	.938 $\pm$ .014	.768 $\pm$ .032	.854 $\pm$ .023	.863 $\pm$ .060	.684 $\pm$ .041	.997 $\pm$ .001	.737 $\pm$ .028
RGBm	TS	.127 $\pm$ .053	.815 $\pm$ .030	.741 $\pm$ .044	.805 $\pm$ .046	.578 $\pm$ .172	.478 $\pm$ .154	.883 $\pm$ .027	.632 $\pm$ .075

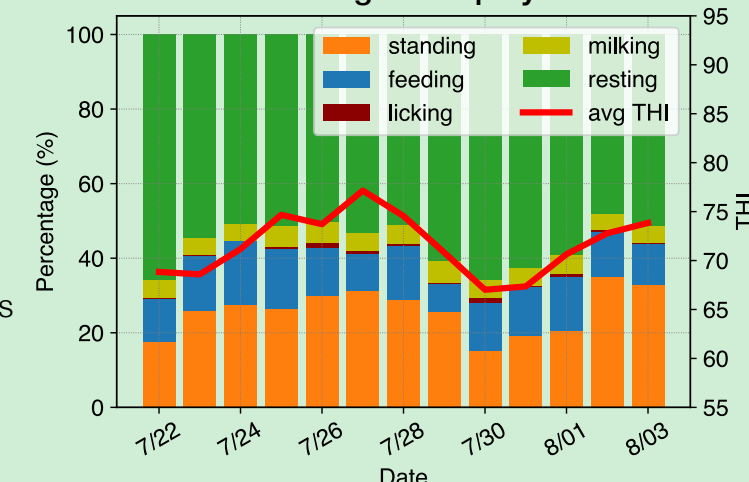
### Single modality results:

- UWB performs the best as the location is useful
- UWB and RGBs outperform IMMU for most behaviors except walking

### Combination results:

- The best model is UWB+HD+AKI
- RGBm performed better than RGBs

### Behaviors of cow #9 vs indoor THI during the deployment



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