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Poster:

Validation Techniques using Wearable Sensors Focused on Evaluating Dairy Cattle Behavior and Welfare: A Scoping Review

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OBJECTIVE

A scoping review of peer-reviewed publications (2009-2022) was conducted to summarize the measurements made and the methods used to validate wearable sensors focused on monitoring dairy cattle behavior and welfare.

APPROACH AND FOCUS

Paper Criteria: Sensors that monitor animal behavior through the use of wearable biometric sensors (Neck, Ear, Leg, Bolus).

Publications: This initial scoping review identified 31 papers published between 2009 and 2022 that validated 17 different wearable biometric sensors.

Data Collection: Information was collected on the "gold standard" sensor validation techniques (in-person observation, video recording, and cross-validation with existing sensors), compared with the behaviors studied, using the performance statistic measurements.

INTRODUCTION

There are growing amounts of wearable sensors used for health and behavior monitoring. 18 validated wearable sensors were identified (Stygar 2021). Understanding animal behavior helps improve animal welfare (Budolfson 2023).

Future research should concentrate on developing and validating PLF technologies dedicated to the assessment of appropriate behaviors and tools focusing on monitoring health and welfare (Styger 2021).

Data standards are required (Siegford, 2023). Research and development needs to focus on identifying the feature candidates of the measures (e.g., deviations from diurnal patterns, threshold levels) that are valid signals of either negative or positive animal welfare (Gómez, 2021) that can be incorporate the five Domains model (Mellor, 2020).

RESULTS

Figure 1: Word Cloud of the behaviors based on number of occurrences in papers

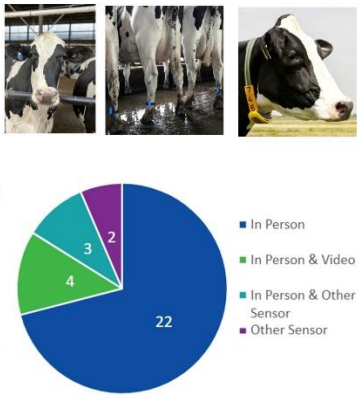

Figure 2: A summary of sensor validation techniques across studies.

Image 1: Sensehub ear, Iceqube leg, and Nedap neck sensors.

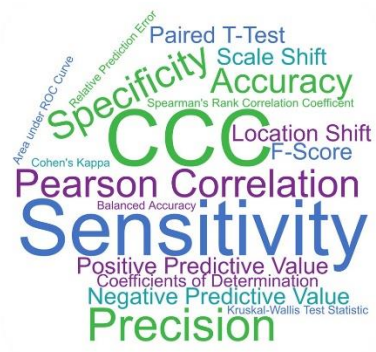

Figure 3: Word Cloud of the "Gold Standard" comparison statistics based on number of occurrences in papers

DISCUSSION

Growing need for consistent validation methodologies

Behaviors that align with the Five Domains Model across the life cycle of species and breed (fetus to EOL)

Over-reliance on in-person observations: Multiple papers monitor the animals simultaneously to address this concern; however, this is not foolproof.

- Combining video recording with sensors improves behavioral monitoring/annotation along with the potential for adding retrospective annotations.

More comprehensive data and model standards: Data and research standards are required to validate wearable sensors, but consensus is needed on:

- How do researchers measure how well a sensor performs?
- How to generate the "gold standard" data to compare with the sensor?
- How do researchers name the animal behaviors/states that they study?

CONCLUSIONS

The validation of dairy cattle wearable sensors should be more reliable and repeatable in terms of methodologies used and reported results.

Greater data standards, validation methodologies, and peer review reporting methods are required for further insights into machine learning for animal welfare and digital welfare auditing.

ACKNOWLEDGEMENTS

Thanks to the AgriGates team, our intern, Alana Lee and Penn State's Dr. Mellisa Cantor for their contributions to this project.

Get a **Copy of Poster**, or find more results and more details on the project team here:

Submitted Abstract:

A Literature Review of Precision Wearable Sensors: Validation Techniques for Evaluating Dairy Cattle Behavior and Welfare.

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With the growth of wearable sensors in Precision Livestock Farming (PLF), there is a need for standardized tools and analytical approaches for validating data used to monitor animal behavior and welfare at the farm level. The objective of this research was to conduct a literature review of all published work in the PubMed database from 2009 to 2022 to summarize validation methodologies used to validate wearable sensors applied to dairy animals for monitoring behavior. An application, scite.ai, was used to sift through a collection of papers based on a calculated impact score to pick the top peer reviewed papers. Of these, 71% (22/31) compared sensor data to in-person observation, and 13% (4/31) used video observation using ethograms for cattle behaviors as the gold standard. Some 6% (2/31) compared their sensor output to another commercially available sensor, while 10% (3/31) also used this method in addition to in-person observations. Validation studies observed 1 to 9 different behaviors. In total, 61% (19/31) measured rumination (rumination, rumination time), followed by eating 58% (18/31; eating, eating time, grazing, feeding), 48% lying (15/31; lying, lying bouts, lying time, resting), and standing 26% (8/31; standing, standing bouts, standing time). A consistent methodology for validating PLF wearable sensor outputs is lacking with a variety of gold-standard comparison methods and different statistical methodologies used. We suggest that standardized definitions for accuracy, bias, precision, and sensitivity and specificity values for research that validates wearable sensors for PLF are needed. Building on these existing studies and current research underway allows for the identification and development of more consistent behavior classification with a focus on improving animal welfare on the farm.

Additional Notes and Results Not in Poster:

Results:

Different Capture Behaviors Grouped:

Behavior Groups	Behaviors in the Groups
Standing	Moving, Standing Bouts, Standing Time, Walking, Standing
Lying	Number of lying bouts, Lying-Down Periods, Lying Bouts, Lying Bout, Percentage of time lying on the right side, Lying Time, Lying LPC, Resting, Total Lying Time, Mean Duration of Lying Bouts, Lying Duration, Lying
Eating	Eating Time, Grazing Behaviors, Feeding Time, Grazing Time, Eating-rumination, Grazing Bites, Grazing, Feed Intake, Eating, Feeding Behavior, Feeding
Ruminating	Ruminating, Rumination Cycle, Eating-rumination, Ruminating Time, Rumination Time, Rumination

Table 1: Different Capture Behaviors Grouped.

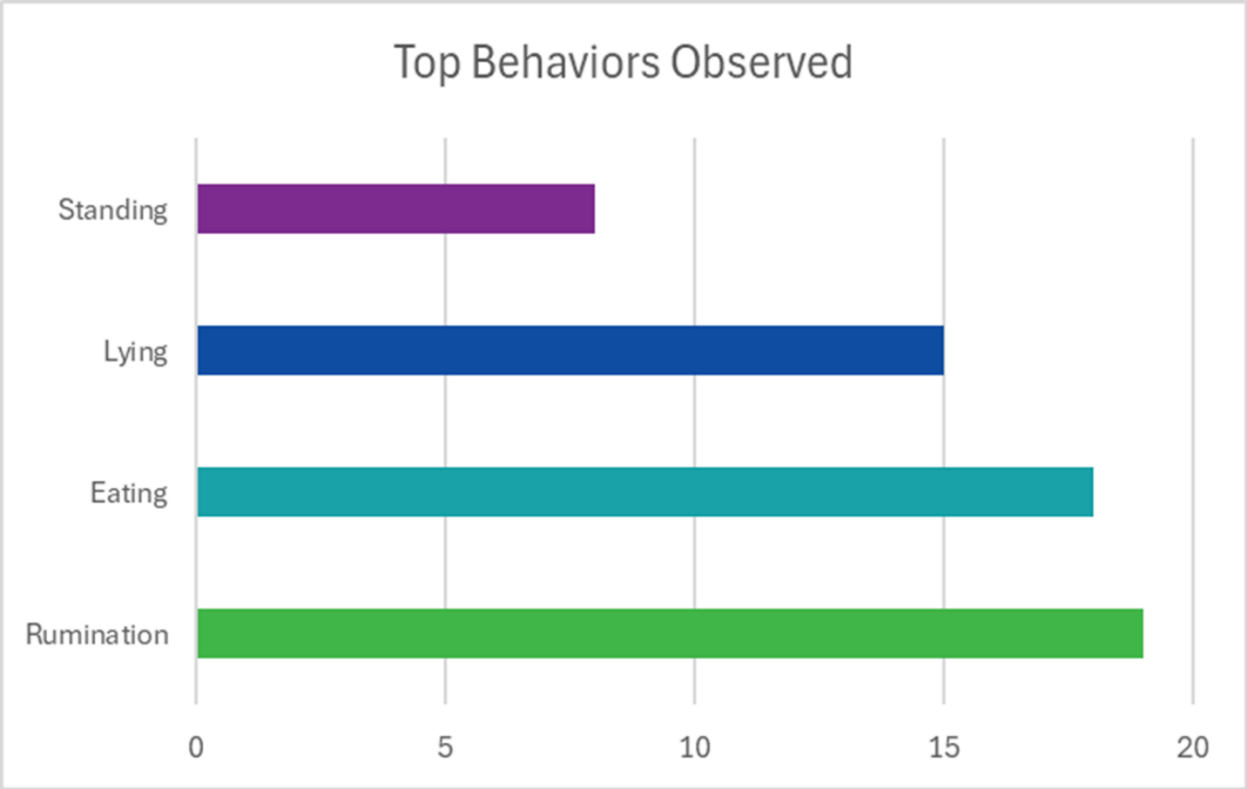
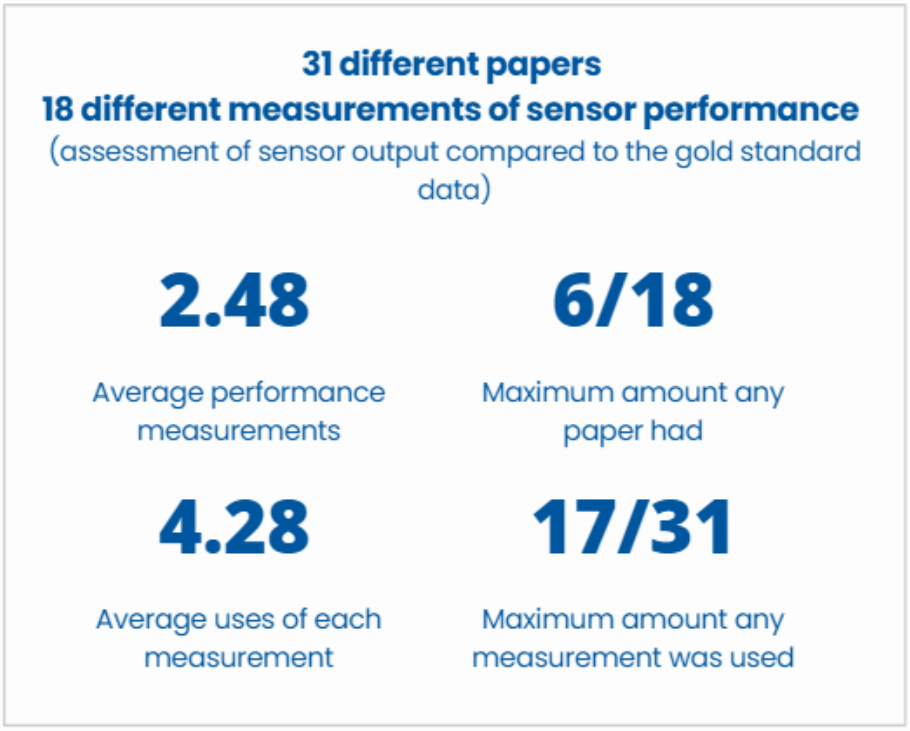


Figure 1: A count of how many papers had each of the top behaviors.



Performance Statistic	Count of uses
Concordance Correlation	17
Pearson Correlation	14
Sensitivity	10
Specificity	8
Positive Predictive Value	4
Precision	4
Accuracy	3
Coefficients of Determination	3
Negative Predictive Value	2
F-Score	2
Paired T-Test	2
Spearman's Rank Correlation Coefficient	2
Maximum Kappa	1
Kruskal-Wallis Test Statistic	1
Cohen's Kappa	1
Area under ROC Curve	1
Balanced Accuracy	1
Relative Prediction Error	1

Table 2: Total performance statics use across 31 papers

List of papers in Review

Lead Author	Title
M.L. Stangaferro	Use of rumination and activity monitoring for the identification of dairy cows with health disorders: Part I. Metabolic and digestive disorders
Ray Adil Quddus	Validation of NEDAP Monitoring Technology for Measurements of Feeding, Rumination, Lying, and Standing Behaviors, and Comparison with Visual Observation and Video Recording in Buffaloes
J.C. Henriksen	Validation of AgiTagII, a device for automatic measuring of lying behavior in Holstein and Jersey cows on two different bedding materials
Per Peetz Nielsen	Technical Note: Validation and Comparison of 2 Commercially available activity loggers
M.R. Borchers	A validation of technologies monitoring dairy cow feeding, ruminating, and lying behaviors
M.A. Reynolds	Technical Note: An evaluation of technology-recorded rumination and feeding behaviors in dairy heifers
G.M. Pereira	Evaluation of the RumiWatch system as a benchmark to monitor feeding and locomotion behaviors of grazing dairy cows
Matthias Steinmetz	Validation of the RumiWatch Converter V0.7.4.5 classification accuracy for the automatic monitoring of behavioral characteristics in dairy cows
Gemma Charlton	Assessing the Accuracy of Leg Mounted Sensors for Recording Dairy Cow Behavioral Activity at Pasture in Cubicle Housing and a Straw Yard
J. Werner	Evaluation and application potential of an accelerometer-based collar device for measuring grazing behavior of dairy cows
Stefanie Ammer	Comparison of different measuring methods for body temperature in lactating cows under different climatic conditions.
Nicola Gladden	Use of Tri-Axial Accelerometer Can Reliably Detect Play Behavior in Newborn Calves
P. Trenel	Technical Note: Quantifying and characterizing behavior in dairy calves using the IceTag automatic recording Device.
Jenny Gibbons	Lying laterally and the effect of the IceTag data loggers on lying behavior in dairy cows
Riaboff L.	Considering pre-processing of accelerometer signal recorded with sensor fixed in dairy cows is a way to improve the classification of behaviors
A. Kok	Technical Note: Validation of a sensor-recorded lying bouts in lactating dairy cows using a 2-sensor approach
Muhammad Wasim Iqbal	Validation of an Accelerometer sensor-based collar for monitoring grazing and rumination behaviors in grazing dairy cows
Said Benaissa	Classidication of ingestive-related cow behaviors usin RumiWatch halter and neck-mounted accelerometers
Salla Ruuska	Validation of a pressure Sensor-based system for measuring eating, rumination, and drinking behavior of dairy cattle
Lorenzo Leso	Validation of a commercial collar-based sensor for monitoring, eating, and ruminating behavior of Dairy Cows
Nils Zehner	Development and validation of a predictive model for calving time based on sensor measurements of ingestive behavior in dairy cows

S. Benaissa	Calving and estrus detection in dairy cattle using a combination of indoor localization and accelerometer sensors
G.M. Pereira	Validation of an ear tag-based accelerometer system for detecting grazing behavior of dairy cows
A. Zambelis	Technical Note: Validation of an Ear-tag accelerometer to identify feeding and activity behaviors of tiestall-housed Dairy cattle
Jorge A. Vazquez Diosdado	Classification of behavior in housed dairy cows using an accelerometer-based activity monitoring system
J.P. Bikker	Technical Note: Evaluation of an ear-attatched movement sensor to record cow feeding behavior and activity
M.R. Borchers	An evaluation of a novel device for measuring eating, rumination, and inactive behaviors in lactating Holstein dairy cattle
C. Goldhawk	Technical Note: Validation of rumination collars for beef cattle
S. Reiter	Evaluation of an ear-tag-based accelerometer for monitoring rumination in dairy cows
Leonie Roland	Technical Note: Evaluation of a triaxial accelerometer for monioring selected behaviors in dairy calves
V. Schweinzer	Evaluation of an ear-attatched accelerometer for detecting estrus events in indoor housed dairy cows.

What's next:

The Project team are working to develop this initial review into a full systematic review which has been started. Reach out at Info@agrigates.io or d.foy@agrigates.io for more information.

Acknowledgments:

To all the AgriGates team, our intern Alana Lee and PSU's Dr Cantor for the support through this project.

References:

- Budolfson, 2023 – Animal welfare: Methods to improve policy and practice | Science
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- Stygar, 2021 – https://www.frontiersin.org/journals/veterinary-science/articles/10.3389/fvets.2021.634338/full
- Gomez, 2021 - A Systematic Review on Validated Precision Livestock Farming Technologies for Pig Production and Its Potential to Assess Animal Welfare - PubMed (nih.gov)
- Mellor, 2020 - Animals | Free Full-Text | The 2020 Five Domains Model: Including Human–Animal Interactions in Assessments of Animal Welfare (mdpi.com)

Team on Project:

Daniel Foy (AgriGates LLC USA)

Daniel Foy (Co-Founder and CEO) is Pennsylvania-based. He is an EAAP PLF study commission officer and a keynote speaker on data value, ML in PLF, data literacy, and data use to improve food animal welfare. With a background in Applied Pharmacology (BSc [Hons]), he has experience in food tech and worked to bring EU AgriTech into the US market. Learn more Here

Matthew Brause (AgriGates LLC USA)

Matthew is a graduate for Colorado School of Mines. He joined AgriGates during his senior year at university in the fall of 2022 as an Applied Mathematician & Software Engineer. Since then, he has been worked on many projects in backend software development and machine learning application, that aid in Precision Livestock Farming application and improve food animal welfare.

Alana Lee (Pennsylvania State University)

Alana is a graduate of animal sciences from Texas A&M University. With a background in beef production, she discovered her passion for dairy cattle as a freshman at TAMU. During her undergraduate studies, she participated in numerous research opportunities, including projects related to Mastitis treatment, nutrition trials, and a research internship with AgriGates on Mapping AgriTech Software and Hardware in Food Animal Agriculture. Alana will enter her master's program at Penn State University under Dr. Melissa Cantor to continue researching Precision Dairy Technology.

Terry Smith PhD, (AgriGates LLC USA)

Terry R. Smith, PhD, (Co-Founder) is a former Professor of Dairy Science at the University of Wisconsin-Madison and the first Director of the University of Wisconsin Center for Dairy Profitability. He co-founded the Pro-Dairy program in NY while on the faculty at Cornell University and has over 45 years of experience in dairy management systems and production economics. Terry founded Dairy Strategies, LLC, a premier business and financial consulting firm aiding dairy producers and agribusinesses globally.

Jim P. Reynolds, DVM, MPVM, Dip. ACAW (AgriGates LLC USA + Western University College of Veterinary Medicine)

Jim P. Reynolds, DVM, MPVM, Dip. ACAW, (Director) graduated as a veterinarian from UC Davis in 1982 and has extensive experience in dairy and beef practice, public health, and academia. Is the Professor of Large Animal Medicine/Welfare at Western University, College of Veterinary Medicine in Pomona, CA. Jim has served in various leadership roles, including chairing committees for the AVMA and AABP, and has received several prestigious awards for his contributions to animal welfare.

Melissa Cantor PhD, (Pennsylvania State University)

Dr. Melissa Cantor is an Assistant Professor in Precision Dairy Science at Penn State University. She has an applied dairy research program that explores the potential of new precision technologies and investigates the impact of disease, precision nutrition strategies, and environment on the health, performance, and welfare of cattle. Cantor has an extension program focused on strengthening stakeholder partnerships throughout the dairy industry including Chair of the PSU Dairy Nutrition Workshop, an editorial board member of J. Dairy Science, a member of the Dairy Cattle Welfare Media Outreach committee, and has two extension programs. Her extension programs focus on "dairy calf success:" including nutrition, health and management, as well as dairy robotics in partnership with U. Penn Drs. Bender, and Rassler. She has 10 PSU extension publications, 22 peer reviewed journal articles, and is a co-author of 2 book chapters. Cantor's expertise focuses in epidemiology, animal behavior, precision livestock farming concepts, OneHealth, and dairy calf nutrition. extension programs. Her extension programs focus on "dairy calf success:" including nutrition, health and management, as well as dairy robotics in partnership with U. Penn Drs. Bender, and Rassler. She has 10 PSU extension publications, 22 peer reviewed journal articles, and is a co-author of 2 book chapters. Cantor's expertise focuses in epidemiology, animal behavior, precision livestock farming concepts, OneHealth, and dairy calf nutrition.