PigNet

Failure-Tolerant Pig Activity Monitoring System
Using Structural Vibration

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Agenda

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2. Hardware Equipment
3. Methodology
4. Evaluation
5. Conclusion

Introduction

Motivation

- Pork accounts for >33% of all meat consumption
- Pig farming is part of a massive industry
- Piglet mortality and growth are major economic factors
- Key period for piglet health:
  - Farrowing: Piglet birth
  - Weaning: When diet switches from milk to other foods
- Tracking piglet health can improve yields

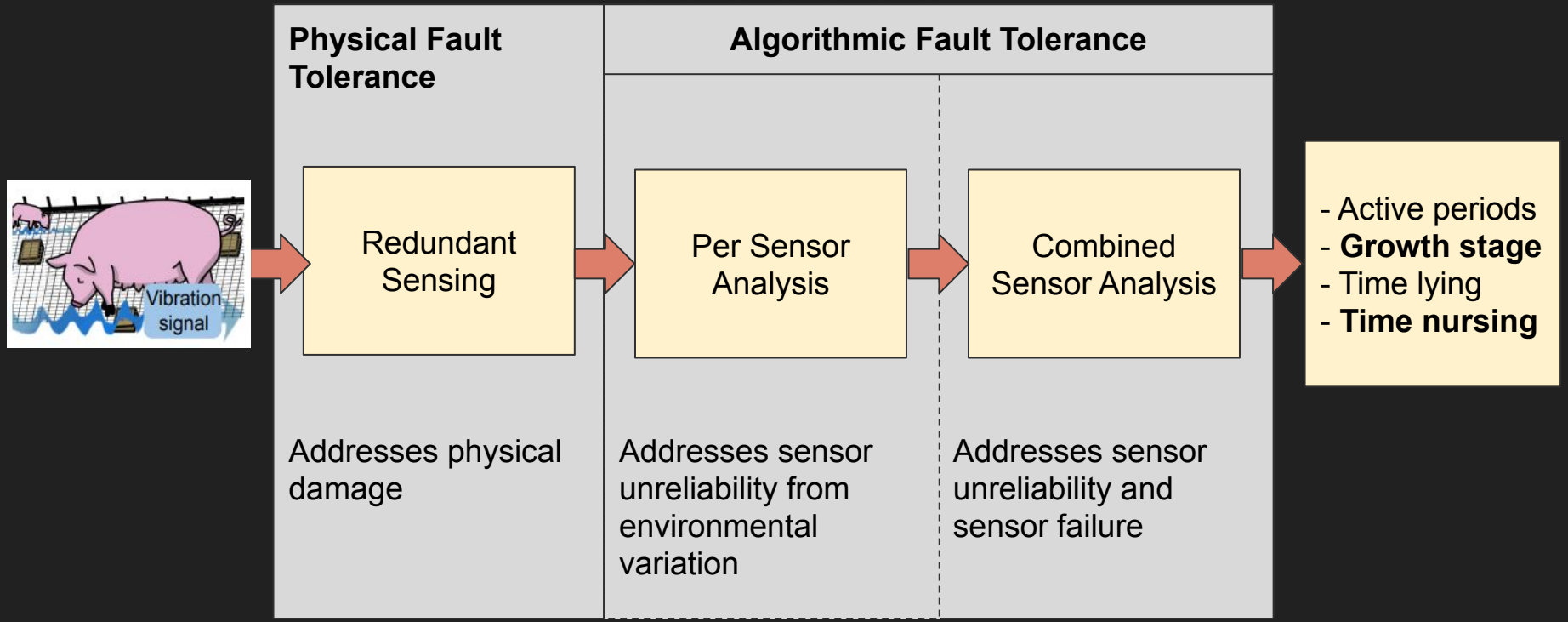
Prior Work

- Camera-based activity tracking:
  - Used in indoor domestic livestock tracking
  - Requires intense processing and storage requirements
  - Requires good lighting - disruptive for animal circadian rhythm
  - Limited by line of sight
- Wearables-based activity tracking:
  - Research standard for livestock tracking
  - Can be chewed or damaged by social animal behaviors
- Photocell movement sensors
  - Only predicts farrowing onset
- Structural vibration sensing
  - Mainly tested for use in indoor human activity tracking
  - Often tested in environments with less noise and hazards
- No prior work automatically detects livestock nursing

PigNet High Level Overview

- Pig activity and growth changes structural vibrations of the pig pen
- Multiple sensors are placed around the pig pen
- Main challenges:
  - Physical fault tolerance: Robustness of hardware to environmental damage
  - Algorithmic fault tolerance: Robustness of algorithms to sensing unreliability

PigNet High-Level Overview



Hardware Equipment

Physical Fault Tolerance

Geophone Sensors

- Vibration signals are collected with **Geophone Sensors**
  - These geophone sensors can detect motion down to 0.1 mm/s
  - Frequently employed for earthquake and seismic activity detection
- This precise motion sensitivity can detect subtle pig motions
  - Subtle head movements is extremely hard to see and is often visually obscured. Computer Vision drastically underperforms for this.
- The geophone sensors have a sample rate between 50 to 500 Hz.
  - The low sample rate allows many more redundant sensors to upload data on a limited amount of bandwidth.

Sensing Nodes

- An outfitted sensor are referred as **Sensing Nodes**.
- An geophone sensor, with amplifiers and ADCs are integrated with a microcontroller, and is outfitted with protective hardware.
  - The sensor node is also simple to produce, and easy to repair.
  - Estimated cost for components per node is around $37
  - This allows multiple sensor nodes to be deployed at a reasonable cost.
- The hardware protection and sensor’s simplicity to deploy multiple redundant sensors are described as PigNet's **physical fault tolerance**.

Methodology

Algorithmic Fault Tolerance

Goal A: Tracking Piglet Growth

PigNet analyses two different types of growth.

- 1. Growth throughout time slots in each day
- 2. Growth throughout different weeks in each pre-weaning period.

Long-term pig growth monitoring are done as three modules.

Data Collection → Group Classification → Sensor Combining

- 1. Characterization of growth-based vibrations
- 2. Supervised learning with clustering for classification
- 3. Combined sensor analysis

Characterization of growth-based vibrations

- How do we characterize the vibrations we see as pigs grow?
- Time-domain, frequency-domain, wavelet-domain, and signal energy physical features from pre-processed floor vibration signals are extracted.
  - Combinations of these four vibrational physical features are used to characterize pig growth.
- A low-pass filter is used to lower sampling rate since growth is decidedly measured over the long-term period
  - Therefore time window for measurements are several hours long.
- This is done as a tradeoff of reducing precise information reading to improve data processing efficiency.

Supervised Learning with Clustering

- How do we categorize our data to stages of growth?
- Growth data is organized based on their time occurrence during the day, and during which weeks in the pre-weaning period.
- PCA (Principal Component Analysis) is used to reduce the dimension of the feature space and to create data clusters
- Because pig growth is known to be a gradual change, KNN (K-Nearest Neighbors) is used to classify growth stages.
    - Deviations from control data clusters are indicators of behavioral abnormalities and health problems.

Combined Sensor Analysis

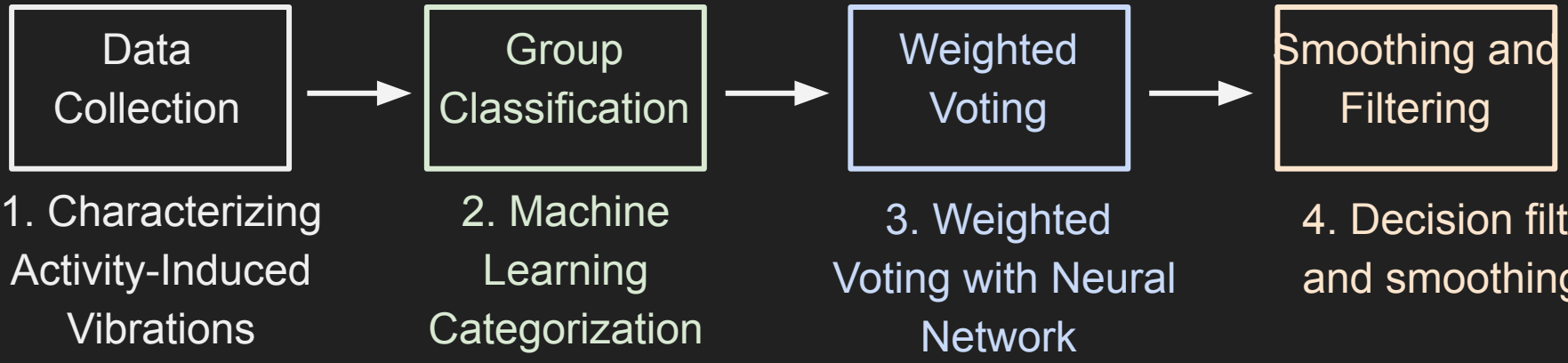
- What constraints are there when we add multiple sensors to collect data on growth?
- Since growth is measured in the span of hours and days, acute events are averaged out throughout the day and are not a concern in evaluating long-term growth.
  - A low pass filter is applied to the data to remove acute events that are not relevant to long-term growth
- Long-term connectivity and reliability are still possible issues of concern.

* Note: Lying as in lying down, to be in a horizontal position.

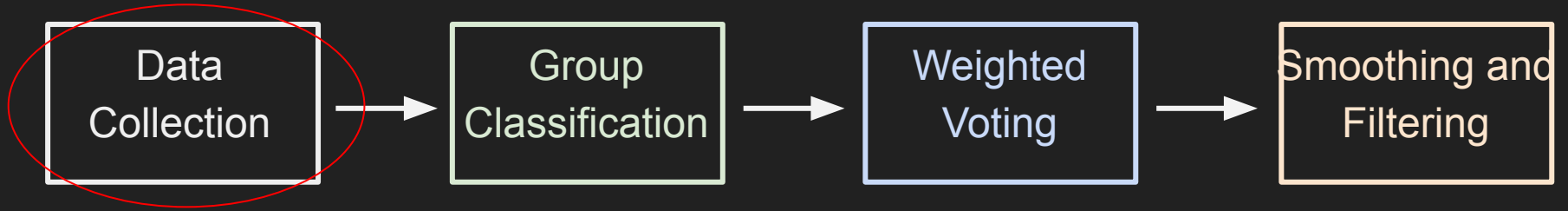
Goal B: Nursing and Lying Detection

- PigNet is also aiming to detect pig activity. {Nursing, Lying} is the Action Set
- The procedure to this is very similar to growth tracking, but with more precise time frame requirements and varying data distributions.
- Additional modifications because categorizing short-term data is more difficult

The framework they use for pig activity monitoring are done as four modules.



Characterizing Activity-Induced Vibrations

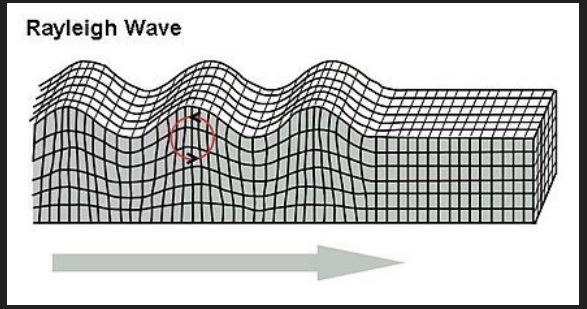


- How do we characterize the vibrations we see in pig activity?
- Activity detection such as Nursing and Lying have to be detected in a much shorter timeframe as compared to pig growth.
  - This means having to read higher frequency impulses
  - Therefore the categorization time frame is reduced to 2 second windows.
- Vibration waves from motion such as nursing are impulses are picked up from high frequencies.
- Vibrations of laying down vs not laying are picked up from lower frequencies

Types of Pig Vibrations

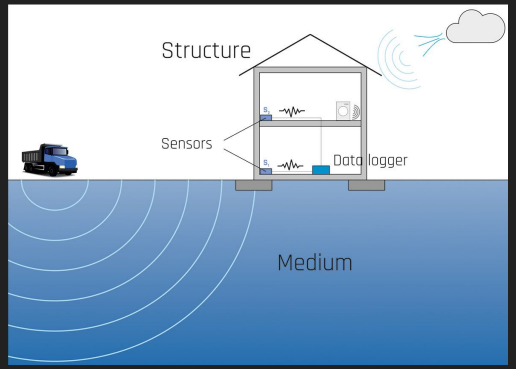
Nursing is an “active” activity
and generates Rayleigh-Lamb Waves

- These are picked up as signal impulses
  - Generated from the pig’s movement transferring vibrational energy into the structure



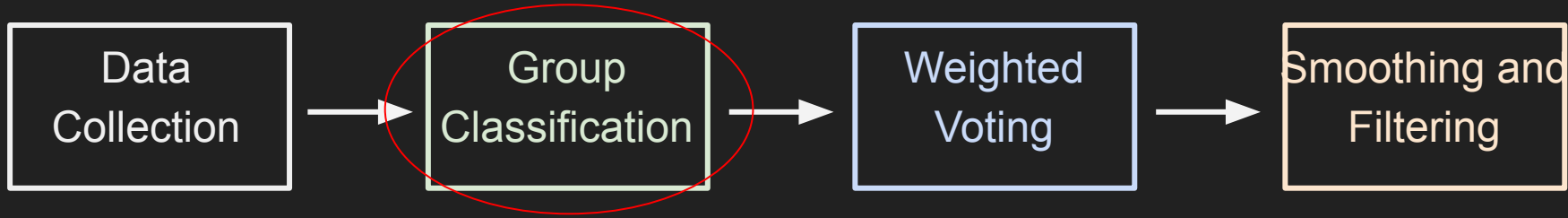
Lying down is a “passive” activity
and changes Structural Ambient Vibrations

- These are picked up by ambient vibration signatures
  - Pigs’ positional weight distribution on the structure causes changes in the wave properties of vibrations passing through



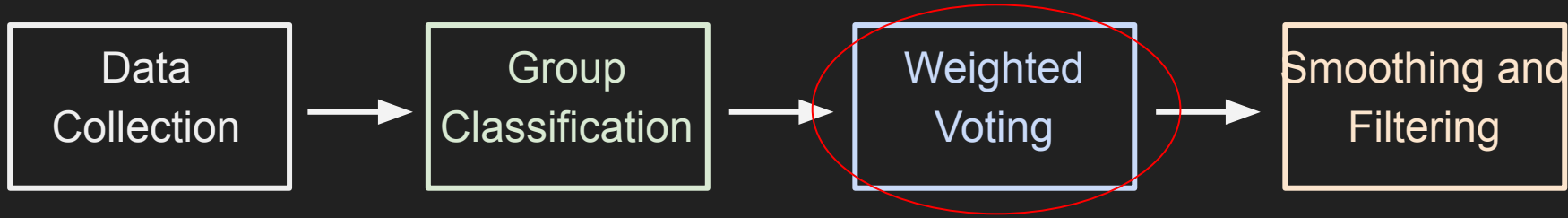
PigNet specifically looks at the frequency bands
that are generated by these two types of vibrations

Machine Learning Categorization



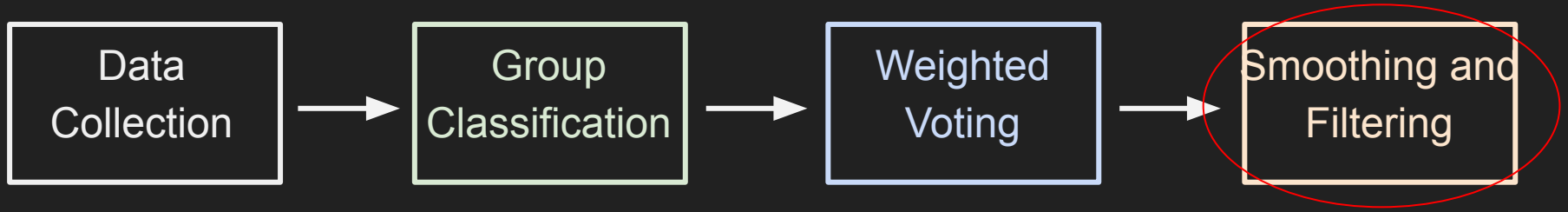
- So now we have our data, how do we classify it for activity recognition?
- Since pig activity data more acute as compared to pig growth, an SVM with a radial basis function kernel is used to build classifiers for each activity.
- This ML learning model suits our specific purposes because:
    - It does not require a large amount of labeled training data.
    - Kernel has with high class separability with nonlinear data
    - It is also very robust to outliers
- Here precision much greatly outweighs data processing efficiency
    - So no low-pass filter is used for this.

Weighted Voting with Neural Network



- We have our classifiers, but our sensors aren't completely reliable.
- To prevent the model from overfitting faulty sensors data, a weighting method that uses a feed forward layer with a fully-connected neural network with one layer.
- The weights are adjusted by the neural network and then combines the classifiers created by the SVM.
- The weights mixed + voting makes the classifiers much more robust to missing sensors.

Decision filtering and smoothing

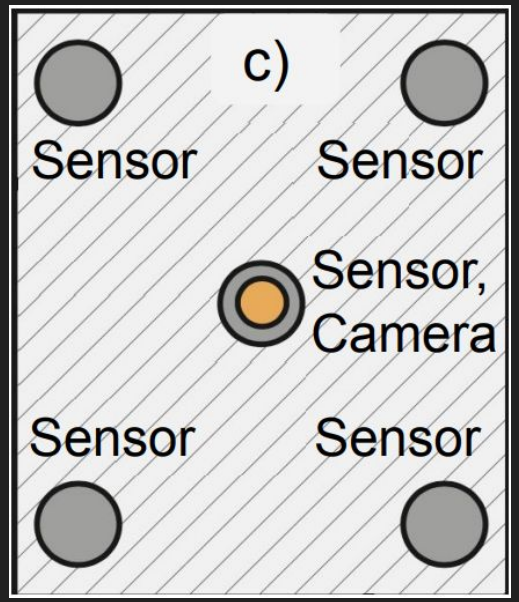


- One more problem, nursing lasts for minutes while lying down could last for more than an hour.
  - Decision bouncing is likely to occur in the initial signal. Detection certainty increases with time.
- A time-based moving consensus filter is used to minimize bouncing
  - A decision is held until for a continuous set number (N_label) of predictions for the other action is detected. This smoothes out the decision output data.
  - The N_label number is based on prior knowledge of each pig behavior.
- Once the data is classified, weighed, and filtered, PigNet now makes a decision on the pig activity.

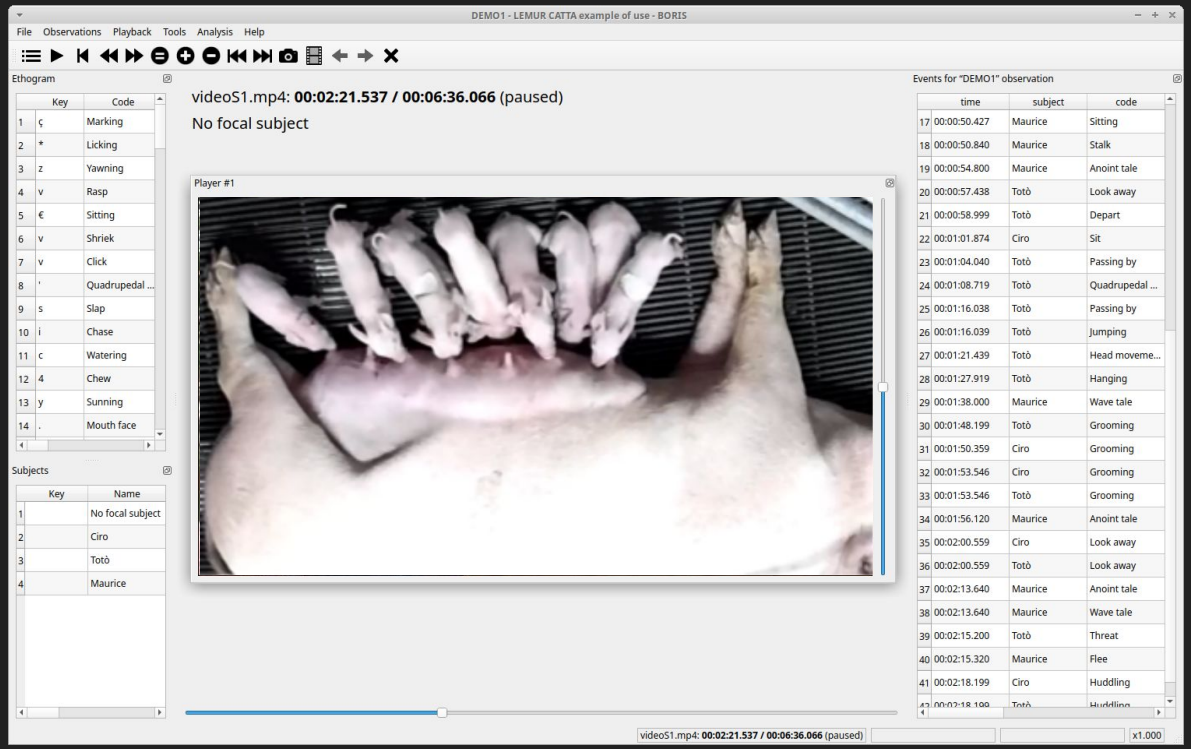
Evaluation

Installation

- Installed in 1 farrowing crate and 2 farrowing pens
- 10 sensors per installation (one in enclosure, one attached directly)



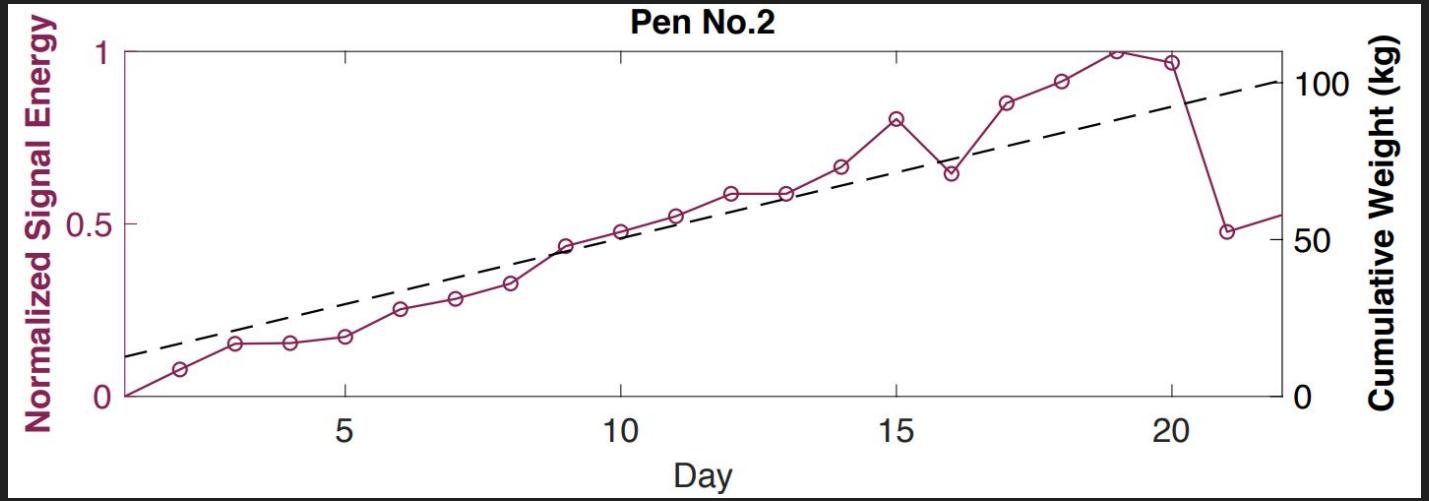
Ground Truth Labeling



Pre-weaning Growth Tracking

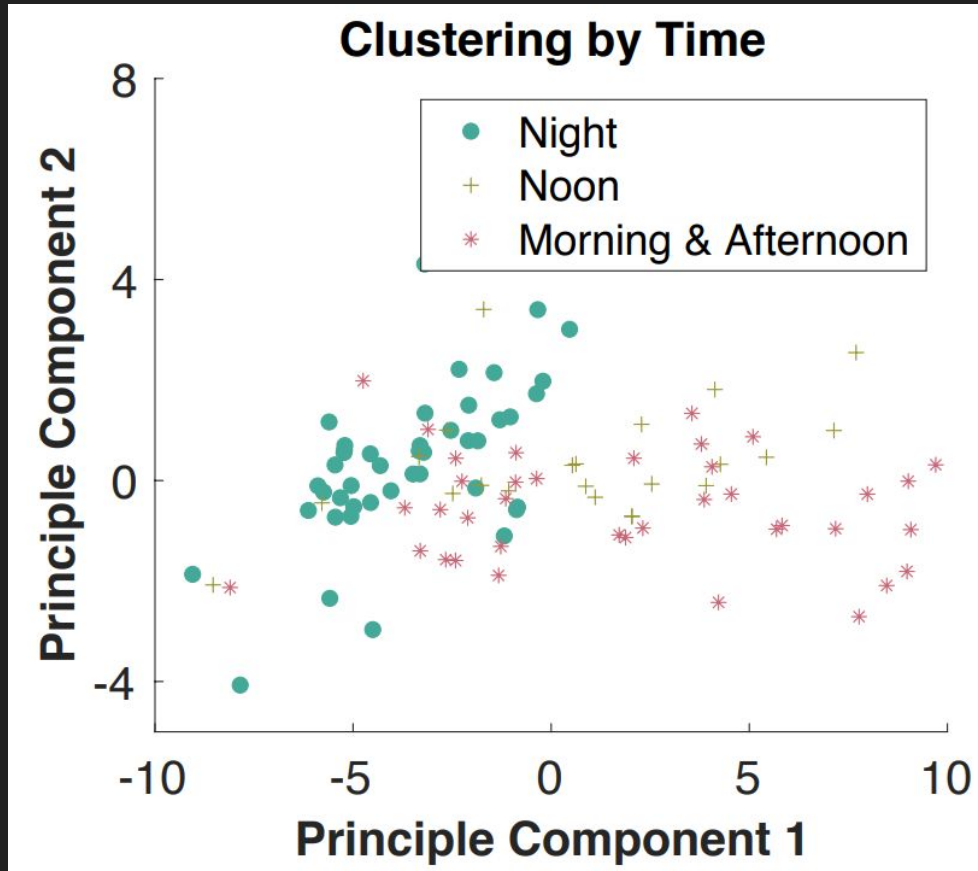
- Ground truth data from weighing piglets from farrowing to weaning
- Anti-aliased downsample to 50Hz isolating 20 Hz baseband
- Statistically significant correlation between signal energy and ground truth

Pen	Correlation Coefficient
1	0.62
2	0.86
3	0.94



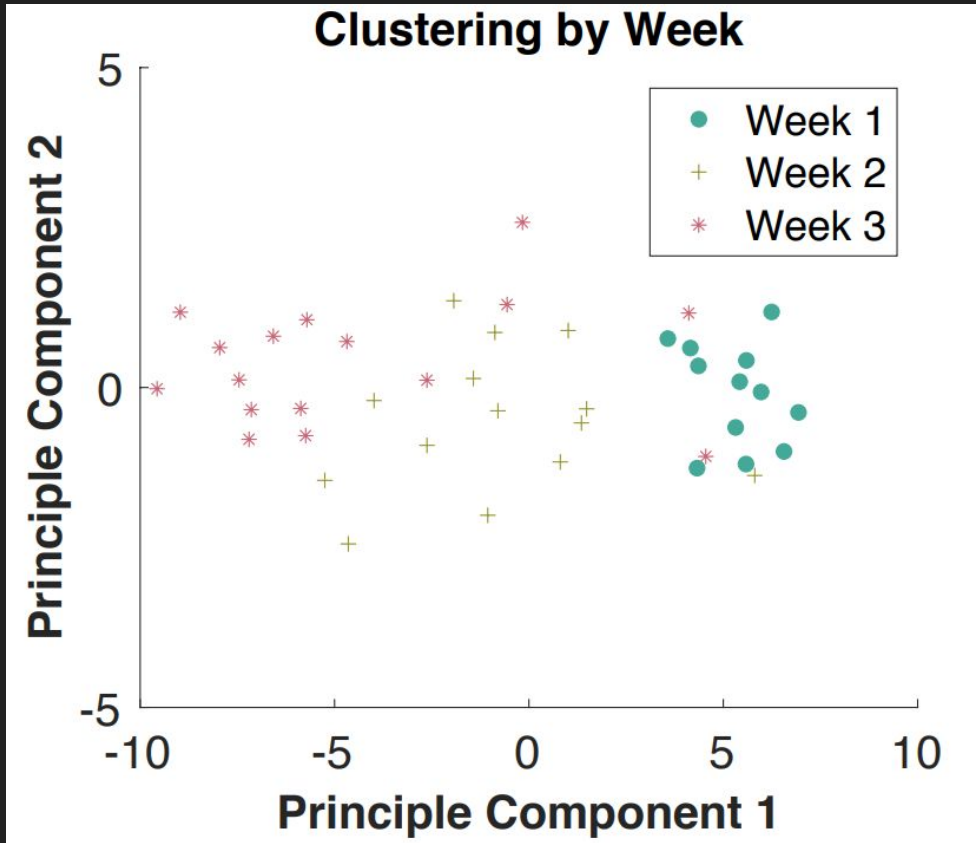
Clustering Analysis: Active Time Prediction

- PCA + k-NN Classification can effectively recover the time of day that a measurement is taken
- 79.1% accuracy



Clustering Analysis: Growth Stage Prediction

- PCA + k-NN Classification can effectively recover the week that a measurement is taken
- 81.8% accuracy

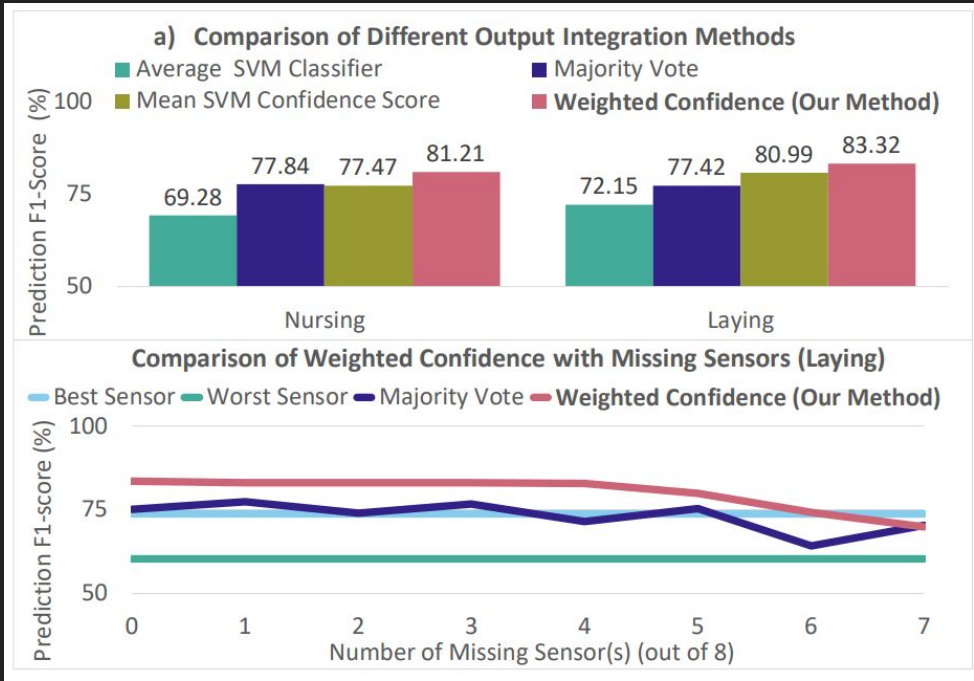


Clustering Analysis

- These clusters are used as a reference for healthy activity
- Measurements outside these clusters considered abnormal behavior

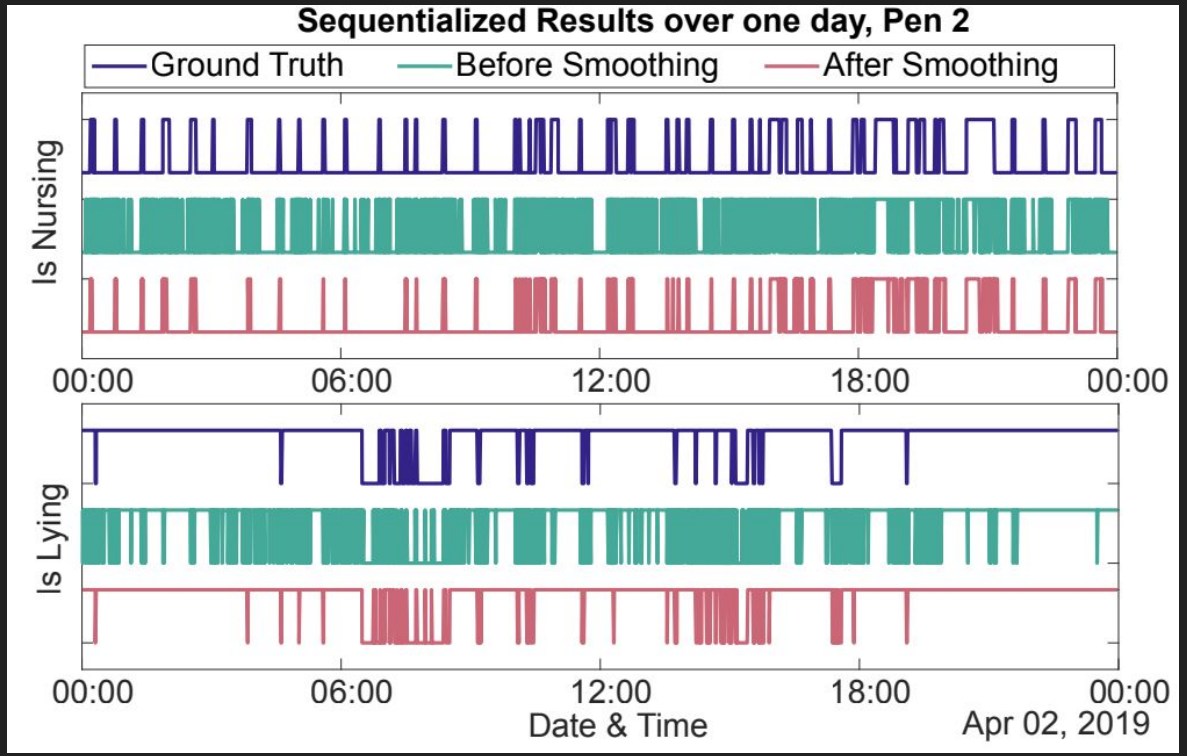
Nursing and Lying Detection

- Different methods to combine SVM outputs evaluated
- Improved accuracy and redundancy with neural weighted confidence method



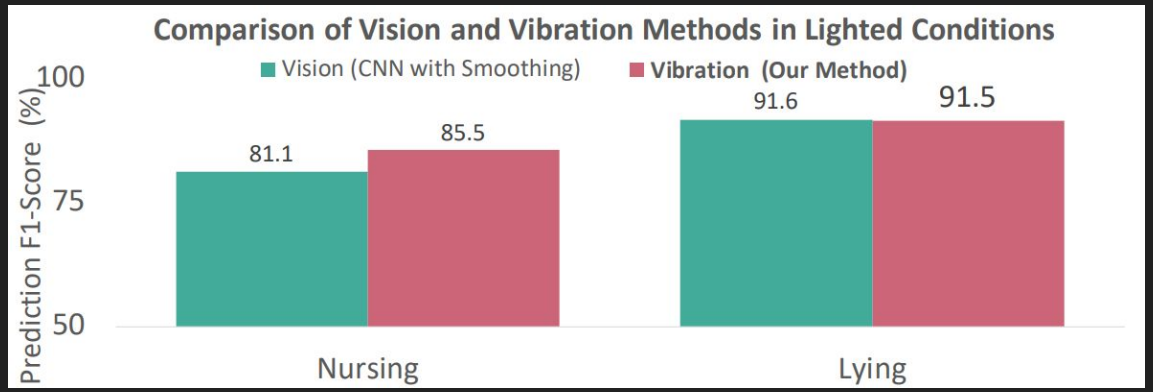
Behavior Based Sequentialization Evaluation

Debouncing the labels removes transients and recovers data that qualitatively agree with ground truth



Comparison with Camera + Convolutional Neural Network

This vibration analysis shows similar or better performance to that of ImageNet trained to classify video frames



	Storage (one minute)	Training Time
Vision	12 mb	504 seconds
Vibration	1 mb	125 seconds

Conclusion

Key Takeaways

- Physical and algorithmic fault tolerance are key challenges
- Researchers tested PigNet in real world conditions
- Developed and tested multiple iterations of hardware to improve robustness
- Key results
  - Predicts weekly pre-weaning growth with 89% accuracy
  - Detects daily nursing activity with 85% accuracy
  - Detects daily lying activity with 91% accuracy

Limitations

- Limited testing: 3 deployments at 1 farm with 2 pens and 1 crate over 3 months
- Pig pens are not standardised across farms
  - Vibrations may not propagate the same
  - Training set was done in the same farm

Ambiguities

- Seemed to imply the system could detect actions other than nursing/lying. Perhaps the classification for those actions was not performing well? Or were the other activities not as useful?
- Last sentence of paper saying their sow lying detection can effectively predict farrowing, but they never discussed this before?