CPS: Synergy: Cost-effective Mastitis Control and Biosecurity for Sustainable Dairy Farming

A data-driven approach to modern agriculture

United States Department of Agriculture
National Institute of Food and Agriculture

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Overview

- Mastitis is the most economically important disease of dairy farms worldwide. The US dairy producers are estimated to lose over $2 billion annually
- Mastitis can be caused by different pathogens through different transmission routes, often being asymptomatic, i.e. subclinical mastitis
- Increase of somatic cells (leucocytes) in milk is an initial indicator of mastitis and somatic cells counts (SCC) are wide used for early detection of mastitis
- Cost-effective, cow-side, real-time monitoring of SCC pathogens and cow activity will significantly improve the control of mastitis in dairy farms

Our Goals

- Build a sustainable cyber-physical system for smart dairy farms that integrates novel **sensing**, **data processing**, **inference**, and **control** approaches, to realize real-time, cost-effective mastitis control and biosecurity

Key Innovation

- **Novel biosensors** for low-cost, cow-side and real-time somatic cell counting (SCC) and multiple causative pathogen identification
- **Topological analysis** of bio-signals for much improved accuracy in pathogen identification
- **Radio-frequency identification (RFID) based localization** system for automatic tracking of the animal-animal and animal-environment interactions
- **Real-time modeling** of the disease propagation dynamics to identify the disease transmission route and sources for isolation and treatment

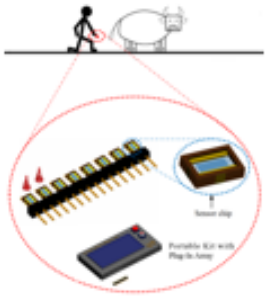
Workflow on Smart Diary Farms

Real time somatic cell counting (SSC) during milking by novel SSC sensor embedded inline.

high SSC

Onsite pathogen detection by ACEK capacitive sensor. Treatment.

normal SSC
Back to milking.

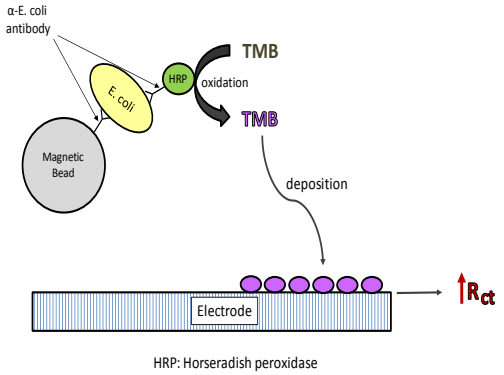


Form action plan.

- Cleaning.
- Testing selected cows.
- Treatment.

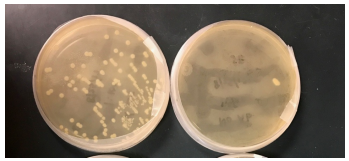
Checking cow activity records.

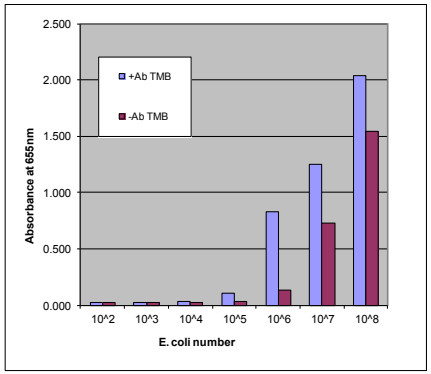
Tracking cow movement to identify transmission sources and routes.



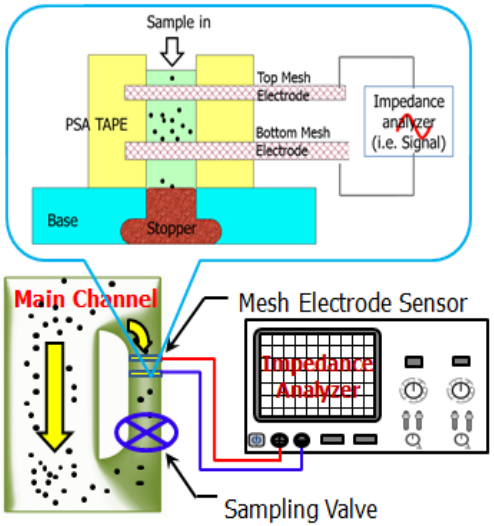
HRP: Horseradish peroxidase

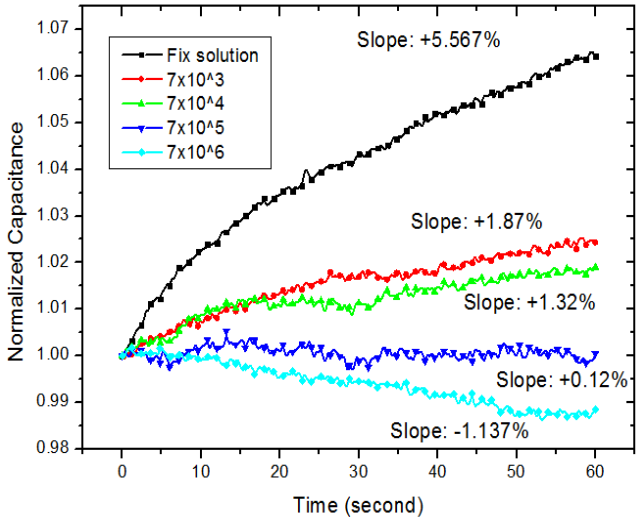
Detection of Escherichia coli via EIS measurement of peroxidase (HRP) reaction

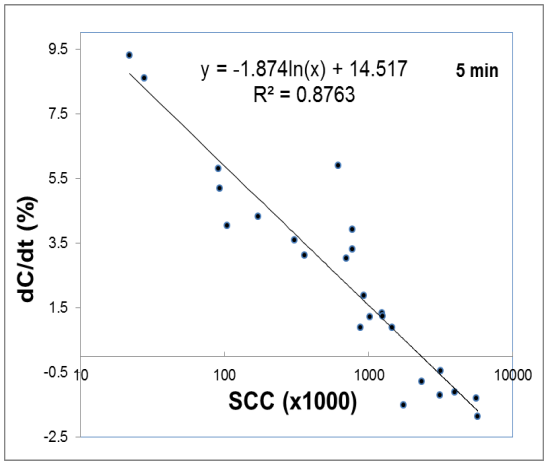




Task: Developing low-cost, cow-side, in-line, quantitative SCC monitoring

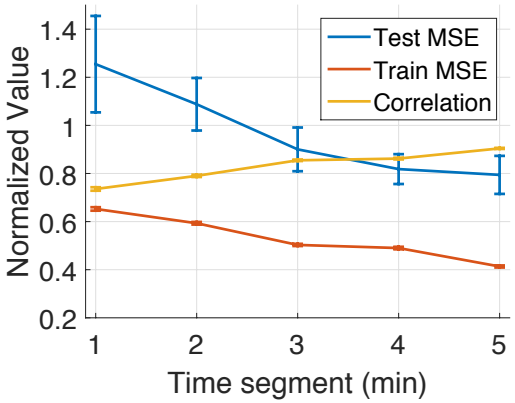


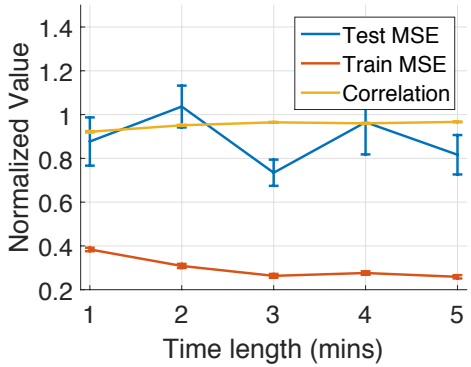




A) In-line somatic cell counter. Top: Cross-sectional view of our SCC sensor; Bottom: its integration into a milking machine. (B) Typical inter-electrode capacitance change with time. Its change rate is dependent on SCC. (C) Blind test results of 25 raw milk samples. Correlation with true SCC found by a flow cytometer is 0.876.

Task: Faster response time with advanced regression





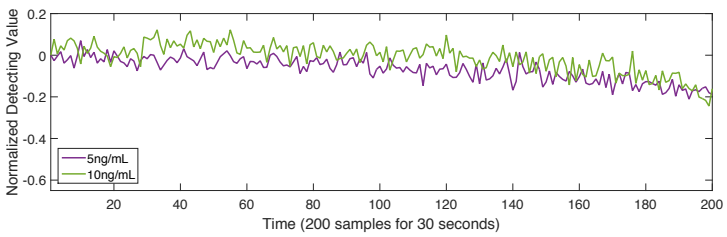
Linear regression	Multi-segment SVM regression
0.7356 ± 0.0717	0.9215 ± 0.0341
0.7902 ± 0.0478	0.9510 ± 0.0264
0.8548 ± 0.0300	0.9646 ± 0.0200
0.8620 ± 0.0347	0.9599 ± 0.0239
0.9043 ± 0.0226	0.9666 ± 0.0174

Comparison between linear regression and multi-segment SVM regression
(A) linear regression (B) multi-seg SVM (C) correlation comparison

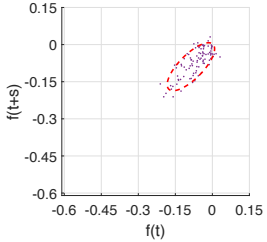
Time period	1st min.	2nd min.	3rd min.	4th min.	5th min.	6th min.	7th min.
Correlation (R^2)	0.5627	0.6773	0.7527	0.7982	0.8763	0.7645	0.6351

Table 1 The correlation between capacitance change rate (dC/dt) and true SCC

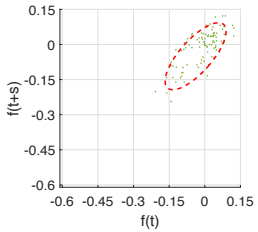
Task: Developing topological features for robust biosignal representation



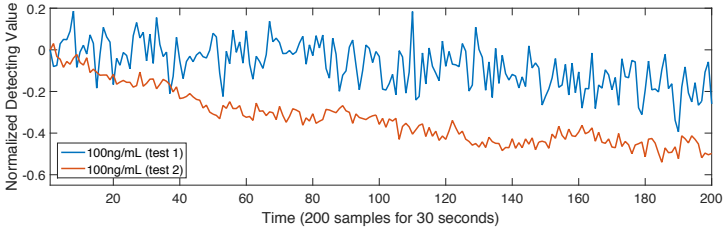
(A) Biosignal with small inter-class variation.



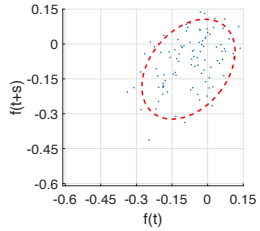
(B) Point cloud (class 1).



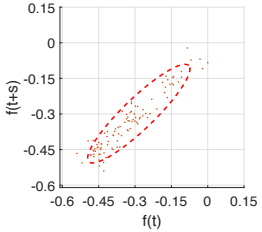
(C) Point cloud (class 2).



(D) Biosignal with large intra-class variation.

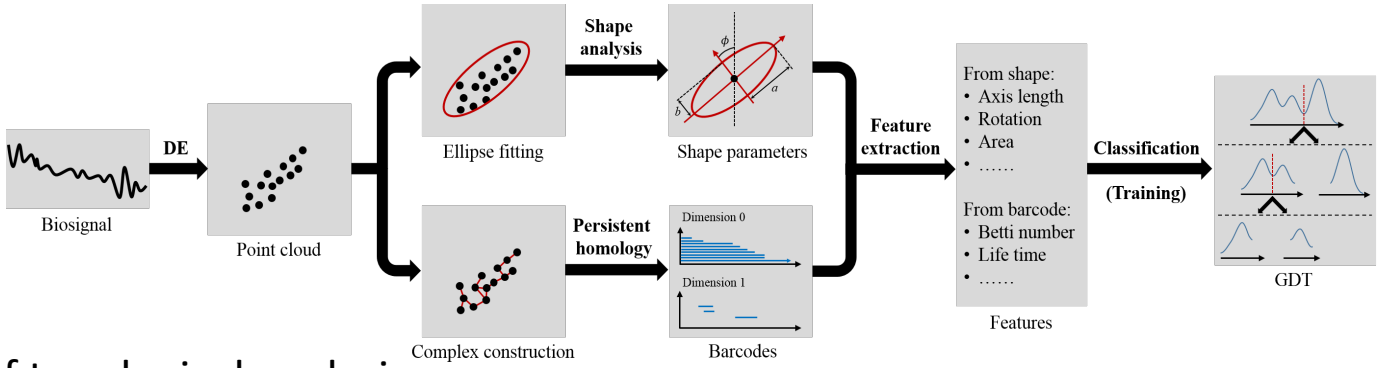


(E) Point cloud (sample 1).



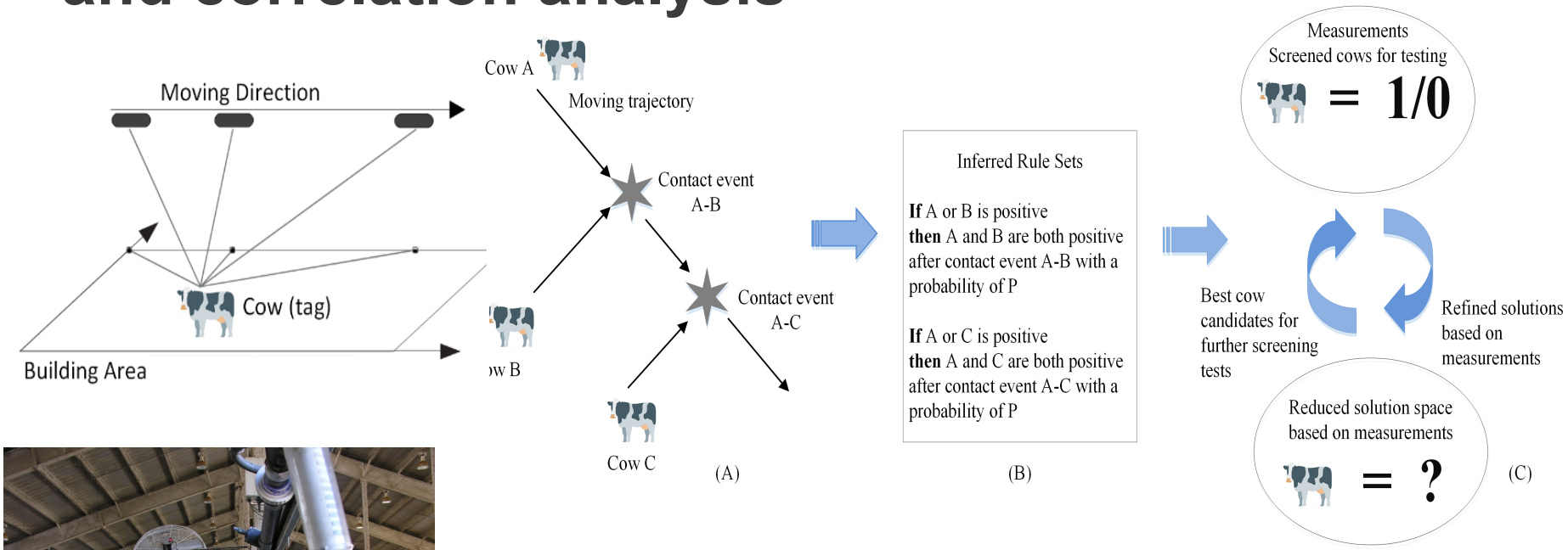
(F) Point cloud (sample 2).

Examples of biosignals and their representation in the topological space



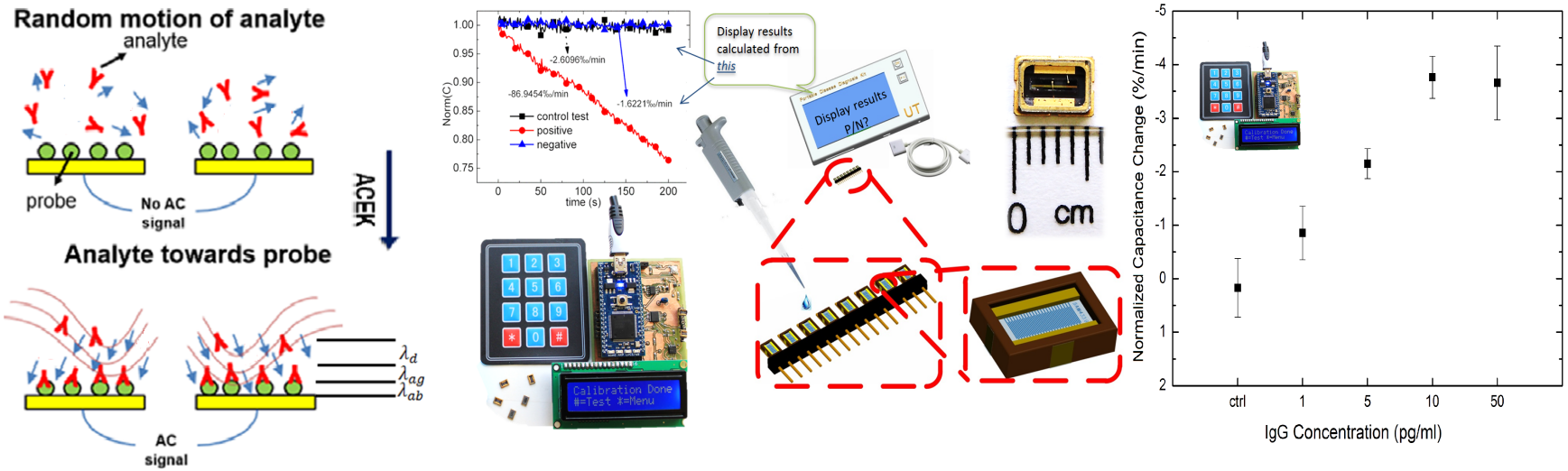
Flow of topological analysis

Task: Developing farm-wide models for cow mobility, pathogen transmission prediction, and correlation analysis



(A) Cow trajectories and contact events. (B) Rules for contact events. (C) Measurement and solution space refinement loop for achieving best results.

Task: Developing point-of-need, low-cost and rapid detection of pathogens



(A) Design of ACEK affinity sensor. ACEK effects produce directed particle movement towards the electrodes for faster binding, and specific binding leads to lower interfacial capacitance C_{int}. (B) System overview of ACEK capacitive sensor.
Middle: concept of the sensing system; Top right: actual electrode chips used in our work; Bottom left: prototyped portable board-level readout system; Top left: Plots of normalized capacitance change with time for positive (red), negative (blue) and control (black). (C) Protein (IgG antibody) detection by board level analyzer. Detection limit is 5pg/mL or 22fM. Detection is done in 30 seconds.

Conclusions of Research Work

- Innovative microfluidic bio-sensing methods integrated with topological classification will enable in-line SCC and point-of-care high-sensitivity detection of pathogen
- The approaches can be extended to other bio-sensing applications, leading to significant advancement in developing low-cost, real-time, high-accuracy bio/chemical sensors
- RFID localization and tracking of cattle movement and disease propagation dynamics modeling can be used for pathogen tracking in general and for farm animals in particular
- High volume of data will be generated from modern farms in real-time, calling for transformative designs on smart diary farms and their practices

Broader Impact

- Mastitis control is of significant economic value, especially to dairy farms, milk production, milk product processing, and crucial to bio-security of the US diary farming industry
- The project provides the US dairy farmers with an integrated low-cost solution for effective detection and therefore control of mastitis, directly contributing to and impacting the sustainability of the dairy industry worldwide
- The developed sensing, computational, and communication technologies are applicable to other domains of agriculture, by transforming them into a control loop with data-driven decision making and actuation
- This research provides interdisciplinary training to both graduate and undergraduate students, and new cross-disciplinary class modules are being developed based on the research findings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Acknowledgements

United States Department of Agriculture
National Institute of Food and Agriculture

- This work is supported through award No. 2017-67007-26150.

Questions?

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