Chemical Sensor Data Processing Using Machine Learning: DCT-based Neural Network & Robust Kernel PCA

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https://sites.google.com/asu.edu/cpsexplosivedetection

Challenge:

- Identify Ammonia Gas Leak Location Using a Crowd-Sourced CPS with Mobile Chemical sensors
- Determine the location of the gas leak using uncalibrated sensors
- Detect anomalous chemical sensors
- Estimate the "sensor drift"

Scientific Impact:

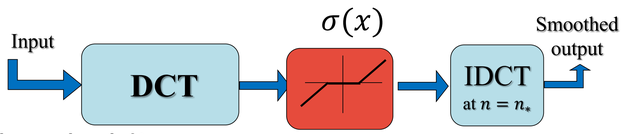
- Developed below-the-threshold gas detection method using deep learning

– Estimated the sensor drift waveform of a given sensor

- Multiplication-free Deep Neural Network
- Multiplication-free Robust L1 based Kernel PCA Method for "anomalous sensor" detection

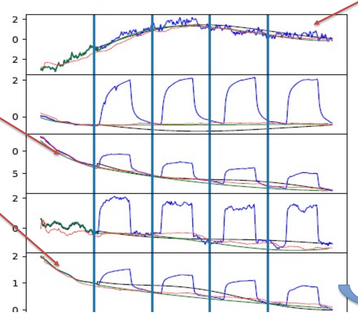
Scientific and Technical Methods:

Deep Neural Network with a Trainable Discrete Cosine Transform (DCT) Layer:



Soft thresholding $\sigma(x)$=sign(x)ReLU$(|x| - b)$

Sensor recordings



- Multiplication-Free L1 Based Kernel PCA: Let $x, y \in \mathbb{R}^N$:

  The vector product $x \odot y := \sum_{i=1}^{N} \text{sign}(x_i y_i) \min(|x_i|, |y_i|)$

- Gram Matrix for anomalous sensor detection:

$$C := \frac{1}{N-1} \begin{bmatrix} x_1 \odot x_1 & x_1 \odot x_2 & \dots & x_1 \odot x_N \\ x_2 \odot x_1 & x_2 \odot x_2 & \dots & x_2 \odot x_N \\ \vdots & \vdots & \ddots & \vdots \\ x_N \odot x_1 & x_N \odot x_2 & \dots & x_N \odot x_N \end{bmatrix}$$

Broader Impact on Society

- Law Enforcement on Crowded Places
- Volatile Organic Compound (VOC) including methane leaks have the same nature as ammonia leaks.
- Methane leaks cause global warming
- Our methods and the CPS can be used in methane leak detection

Broader Impact on Education:

- Used sensor data in a new neural networks and DSP courses at UIC
- Supervised Undergraduate Students:

Robotic Air Purifier (Puribot):

https://engineeringexpo.uic.edu/news-stories/robotic-air-purifier/

https://drive.google.com/file/d/1PUfA-OH9VPyMNkR-xFij5uK0HO4ezKgK/view

References:

- Badawi, Diaa, Agamyrat, Agambayev, Sule Ozev, and A. Enis Çetin.. "Discrete Cosine Transform Based Causal Convolutional Neural Network for Drift Compensation in Chemical Sensors." In ICASSP 2021-2021 IEEE International Conference on Acoustics, Speech and Signal (accepted for publication).

American Chemical Society Interview:

- https://cen.acs.org/analytical-chemistry/chemical-sensing/Neural-network-measures-gas-below/98/web/2020/05
- The interview is based on our 2019 IEEE Access paper describing the neural network-based processing of chemical sensor data:

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