Karlsruher Institut für Technologie

Printed Electrodermal Activity Sensor with Optimized Filter for Stress Detection

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2022iswc

Long-term, continuous, unobtrusive **stress detection** is important

Current Solution: smart watch/ wristband

price: €400 for apple watch, €1500 for Empatica wristband

wearability: non-flexible housing
large size

printed electronics

ultra-low cost

flexibility

non-toxicity

Stress Detection

Sensor **Printed electrodermal activity sensor**

Electrodermal activity sensor

Skin conductance that related to the sympathetic neural activity

Algorithm **Printed band-pass filter + threshold**

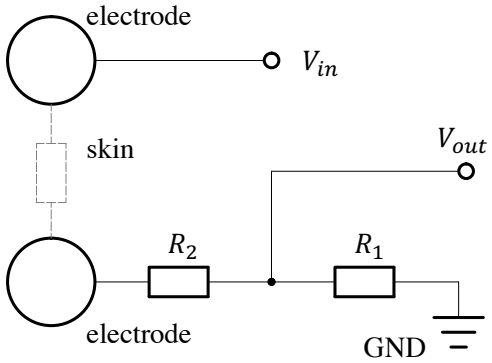
Classic machine learning

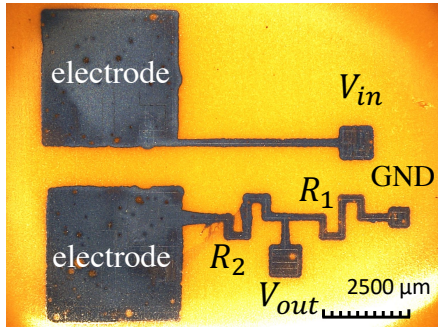
Random forest, AdaBoost, Decision tree, …

Artificial neural network

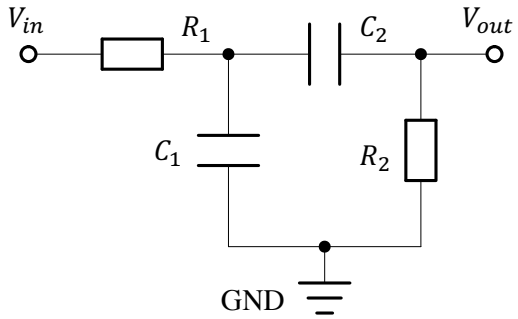
CNN, RNN, …

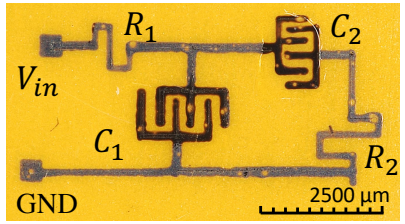
Printed electrodermal activity (pEDA) sensor

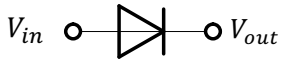


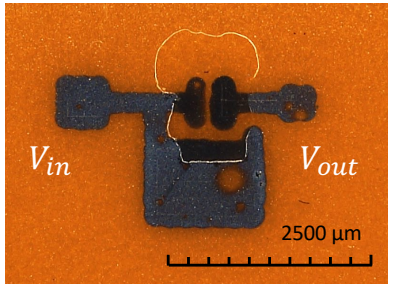


Printed band-pass filter & printed diode









Hardware level optimization

Band-pass filter

System model

$$\dot{\boldsymbol{z}} = \begin{bmatrix} -\dfrac{R_1 + R_2}{R_1 R_2 C_1} & \dfrac{1}{R_2 C_1} \\ \dfrac{1}{R_2 C_2} & -\dfrac{1}{R_2 C_2} \end{bmatrix} \cdot \boldsymbol{z} + \begin{bmatrix} \dfrac{1}{R_1 C_1} \\ 0 \end{bmatrix} \cdot V_{in}$$

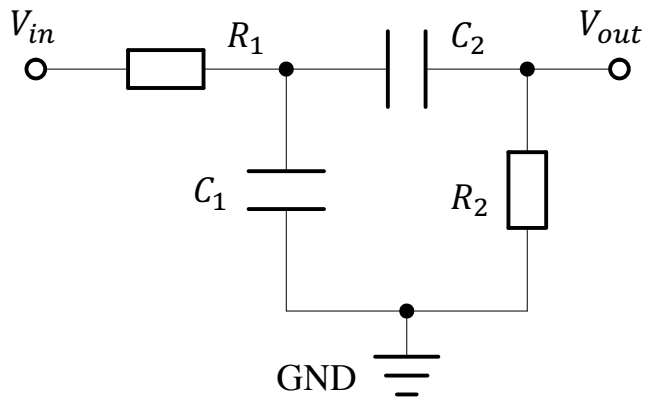
$$V_{out} = [1 \quad -1] \cdot \boldsymbol{z}$$

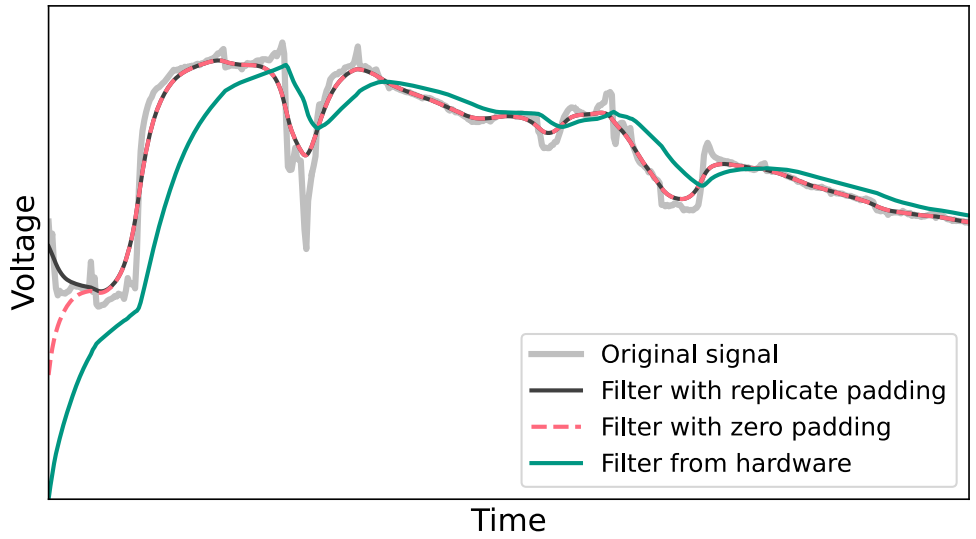
where $\boldsymbol{z}$ is the state vector

Objective function

$$\min \sum_t f(\boldsymbol{p}, V_{in}, t)\,(1 - 2y_t)$$

f: summarizes the system model of filter
$\boldsymbol{p}$: vectorizes the design parameters of filter
y_t: label at t, 1 for stress, 0 for non-stress





Comparison of convolutional filter and hardware filter

Hardware level optimization

Band-pass filter

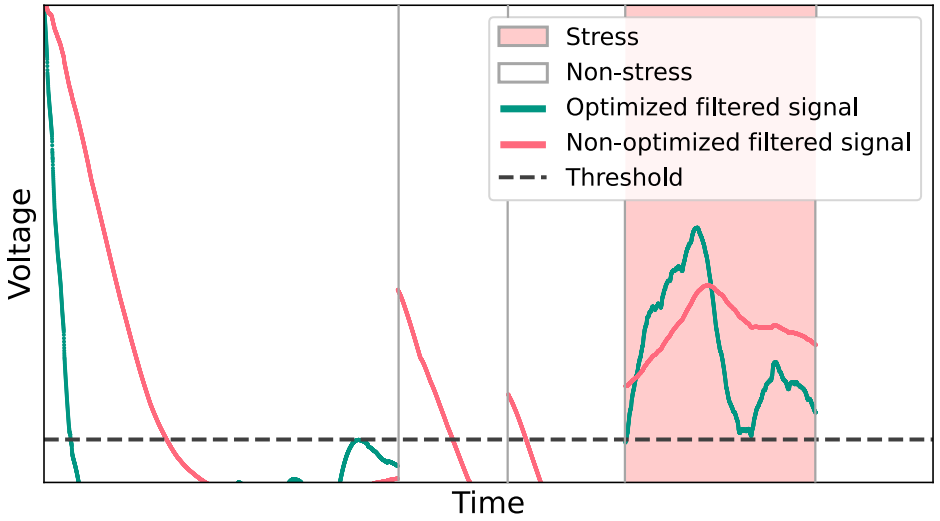
Objective function

$$\min \sum_{t} f(\boldsymbol{p}, V_{in}, t)\,(1 - 2y_t)$$

differential equation
no closed form

Optimization

Covariance matrix adaptive evolution (CMA-ES)



Data source: WESAD dataset

Threshold diode

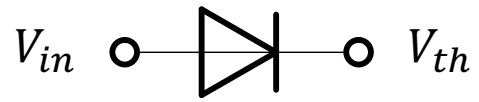
Objective

higher threshold -> higher precision, lower recall
lower threshold -> lower precision, higher recall

→ trade-off: **F1 score**

Optimization

grid search



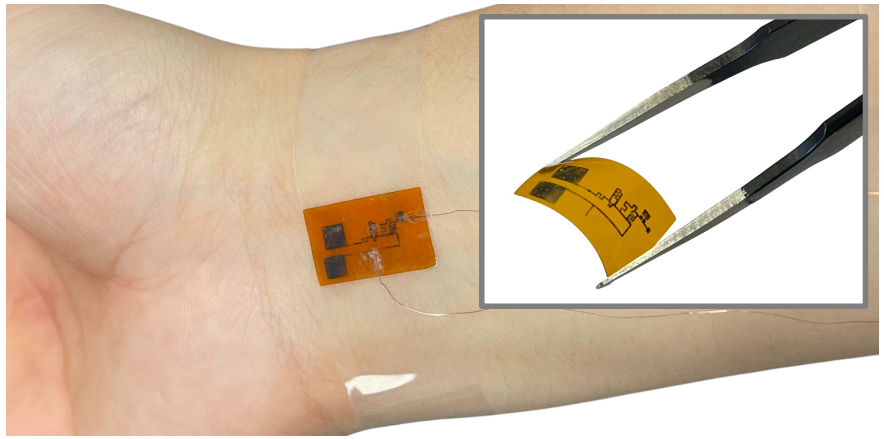
Feasibility Test

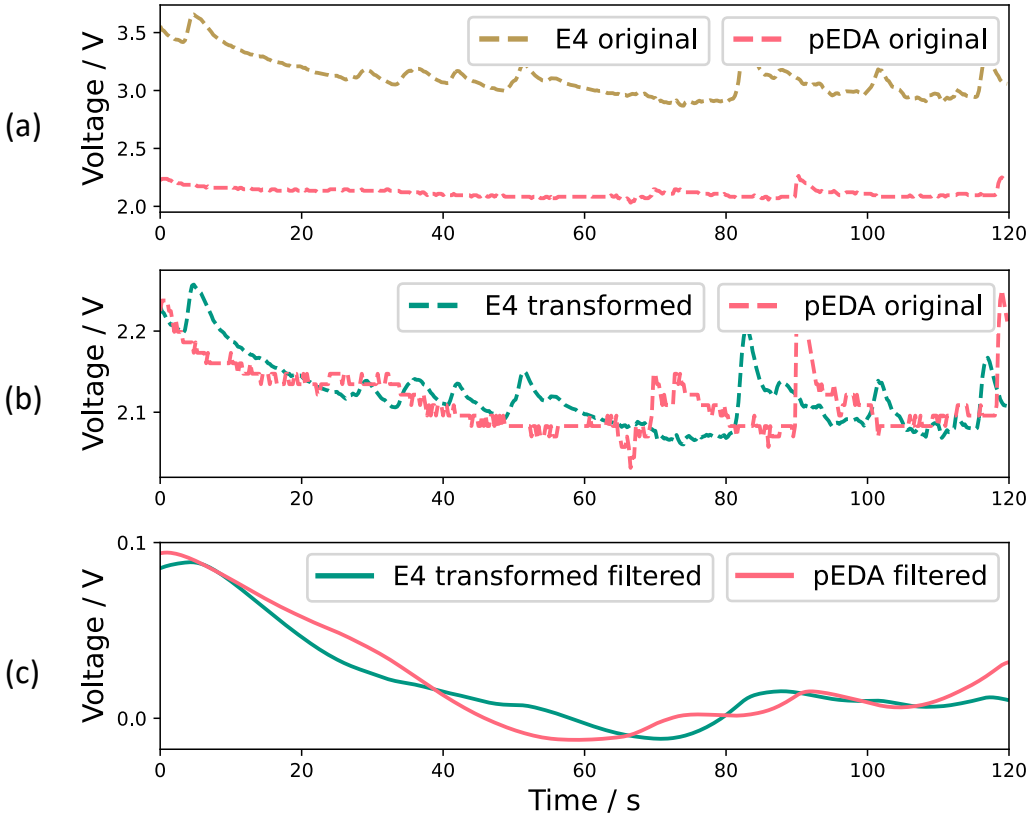
EDA signal -> pEDA signal

collect data with **pEDA** and E4 at the same time (N=3)

find transformation from E4 signal to pEDA signal

$$\hat{x}_{pEDA} = \omega_1 \cdot x_{E4} + \omega_2$$





The proposed pEDA sensor can obtain comparable information to that of the state-of-the-art Empatica E4 wristband.

Future works

simulation -> real test on hardware

more sophisticated but dependable filters

take production error into optimization process

printed/soft battery

Thank you for your attention