Biosensori e ricerca clinica: opportunità e problematiche

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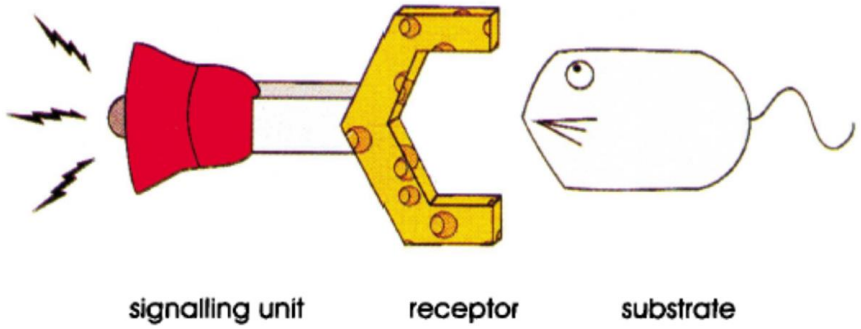
What is a chemical sensor?

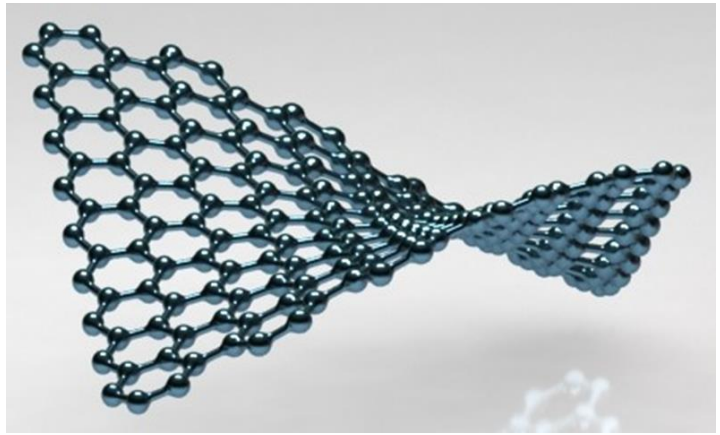
"a small device that as the result of a chemical interaction or process between the analyte and the
sensor device, transforms chemical or biochemical information of a quantitative or qualitative type into an analytically useful signal"

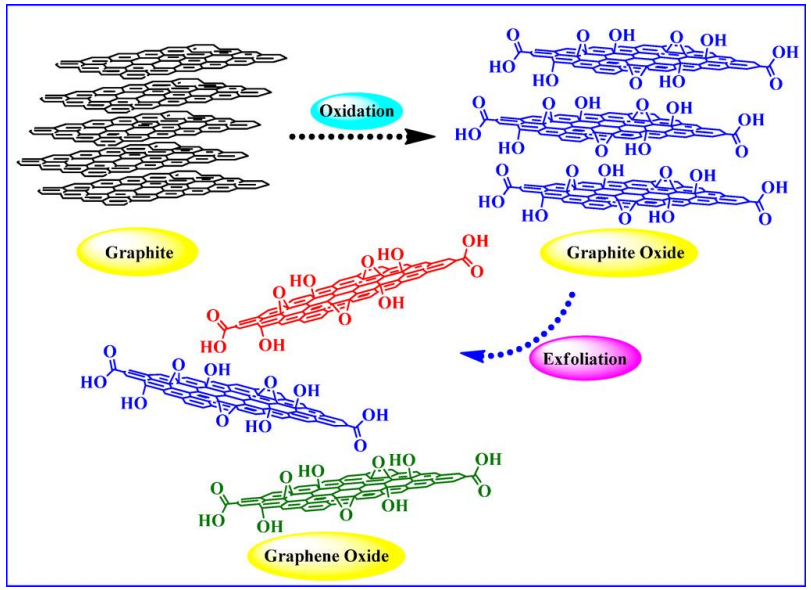
Stetter JN, Penrose WR, Sheng Y. Sensors, chemical sensors, electrochemical sensors, and ECS. J Electrochem Soc 2003;150:S11–6

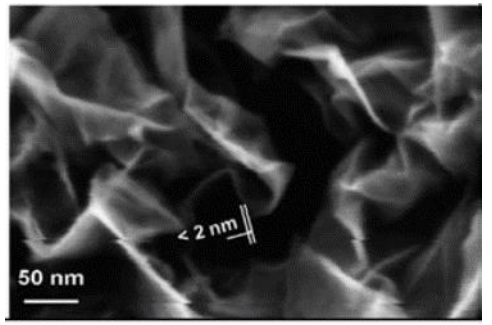


Innovative sensitive materials

Graphene

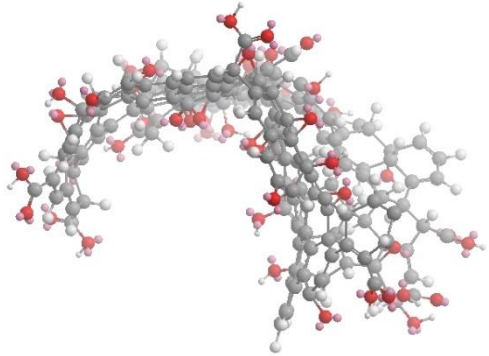






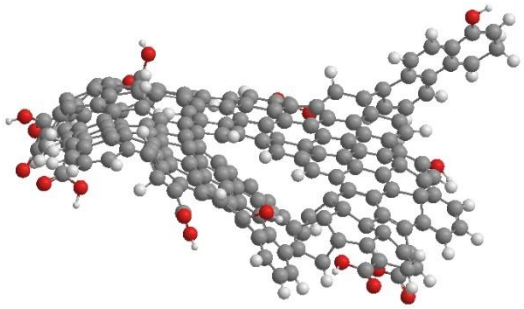
Andre Geim

Konstantin Novoselov



Graphene oxide

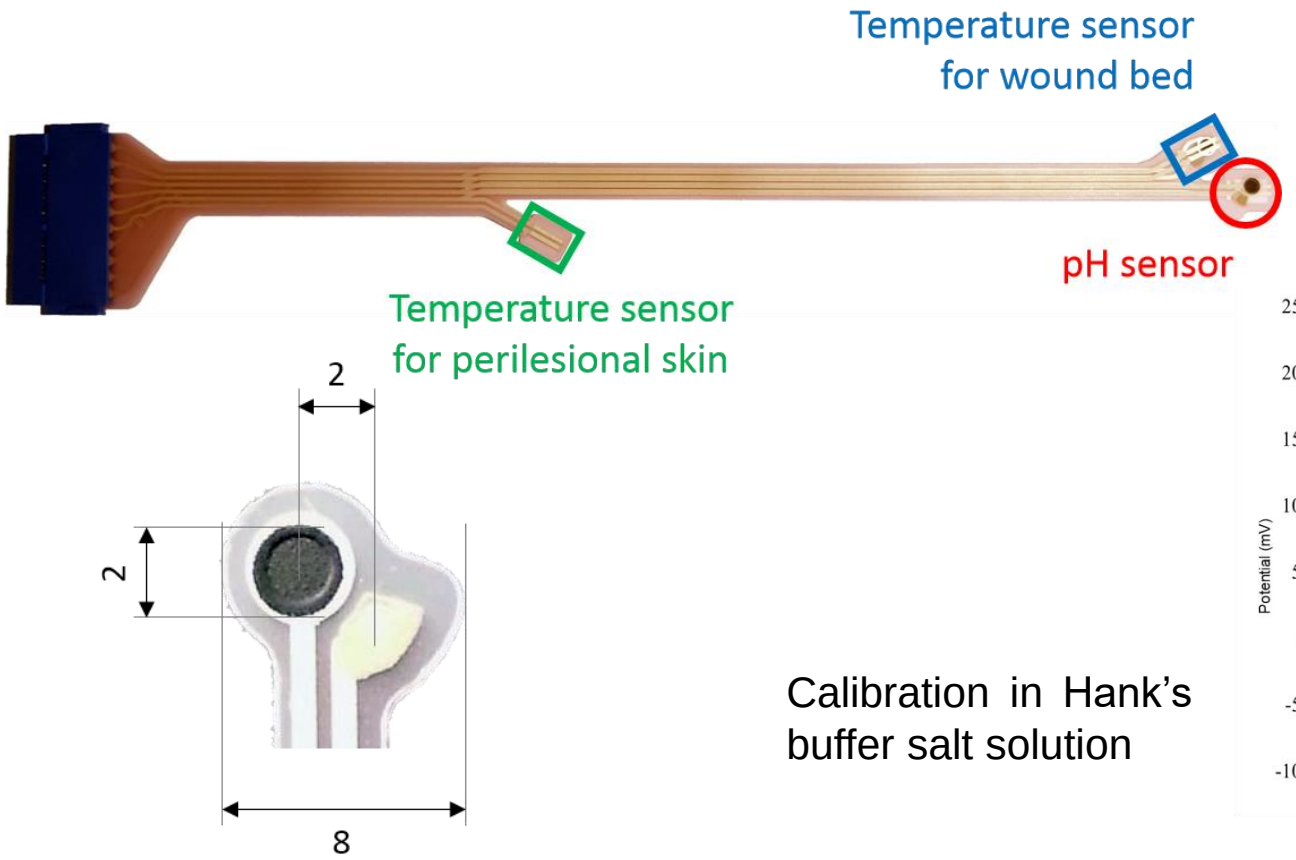
Reduction



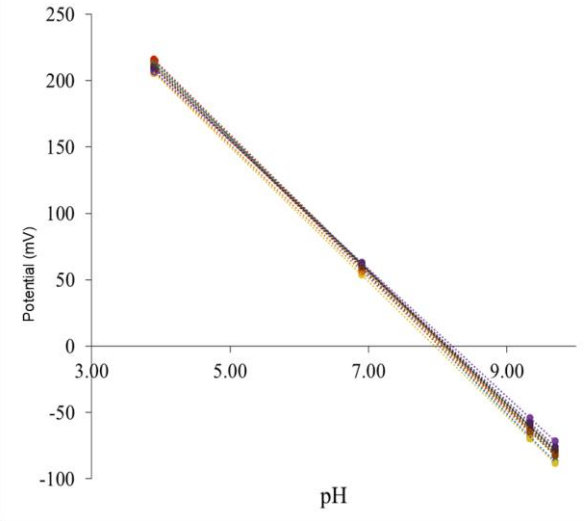
Reduced graphene oxide

Fabrication of sensors

GO films were deposited by drop casting; for temperature sensing, GO films were reduced by a water solution of ascorbic acid (25 mg/L, 20 minutes at 80 °C)[1].



Calibration in Hank's buffer salt solution

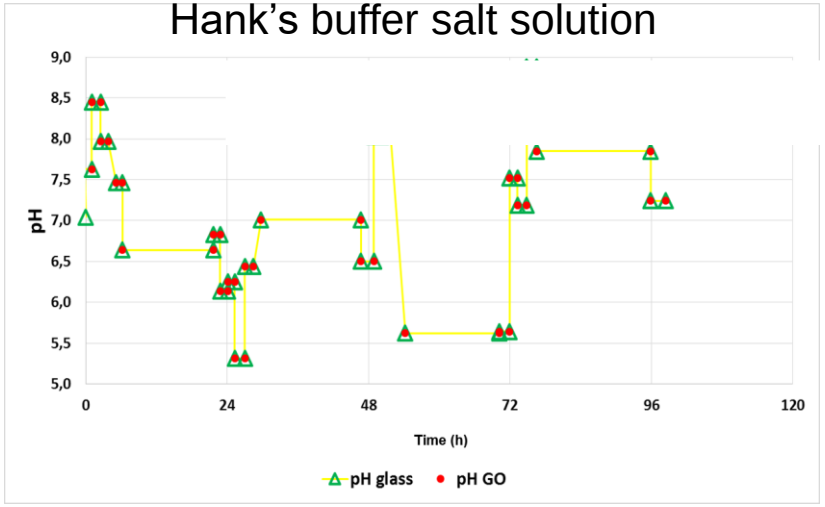


Sensor	Sensitivity (mV/pH)
1	52.1
2	50.3
3	50.7
4	50.1
5	51.4
6	48.1
7	50.2
8	50.5
9	50.7
10	50.6
11	49.7
12	49.3
Average	***50.3***
St. dev.	***1.0***

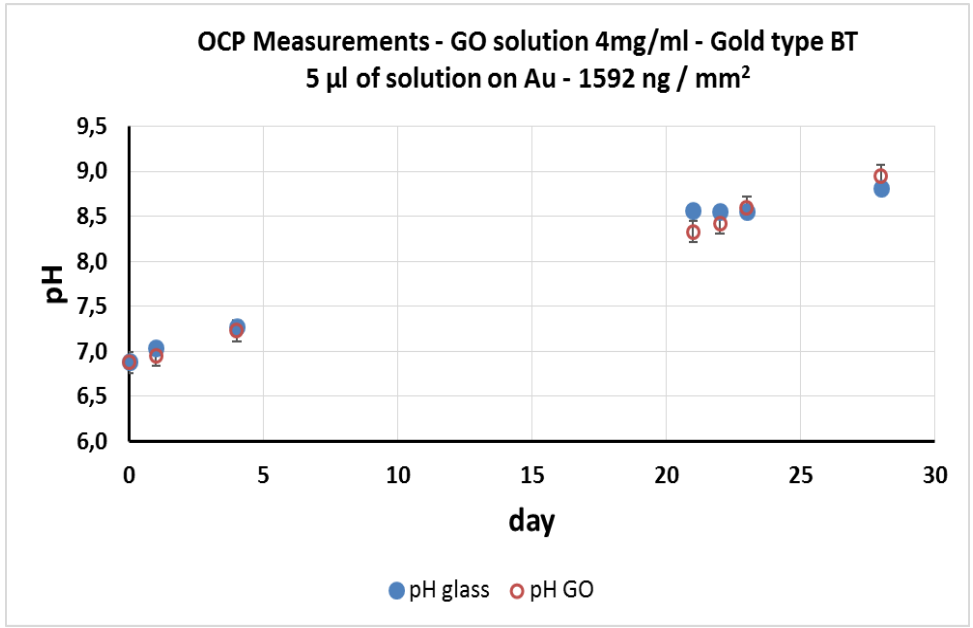
P. Salvo et al. Temperature and pH sensors based on graphene-like materials for monitoring chronic wounds, Biosensors & Bioelectronics 91 (2017) 870-877

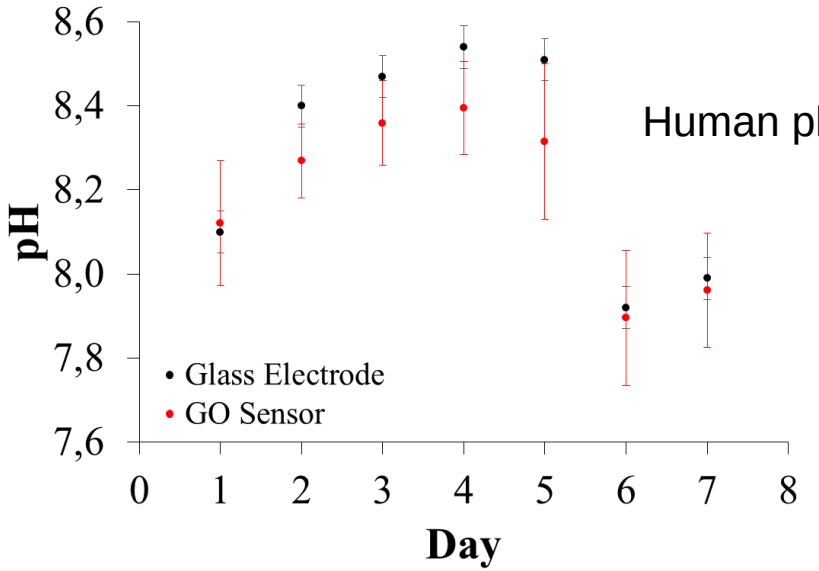
Validation and test in biological specimen

Hank's buffer salt solution



Wound exudate

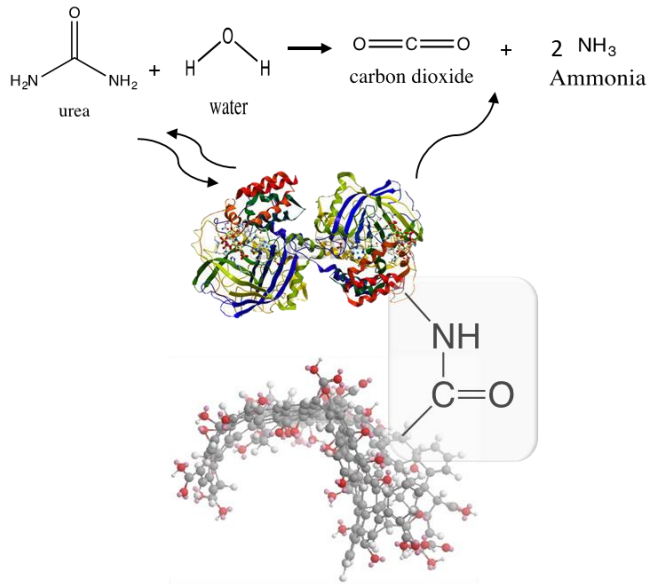


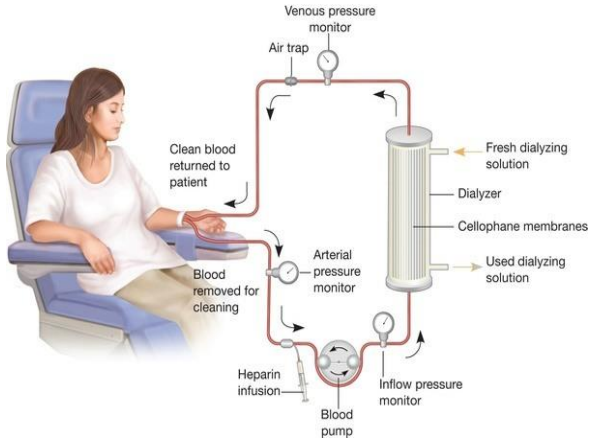


Human plasma

Wound bed

From sensors to biosensors

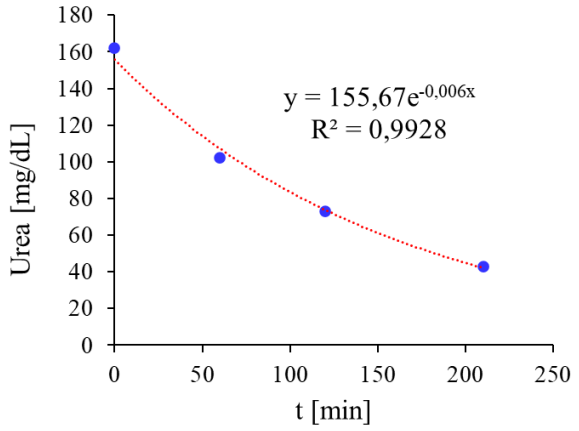




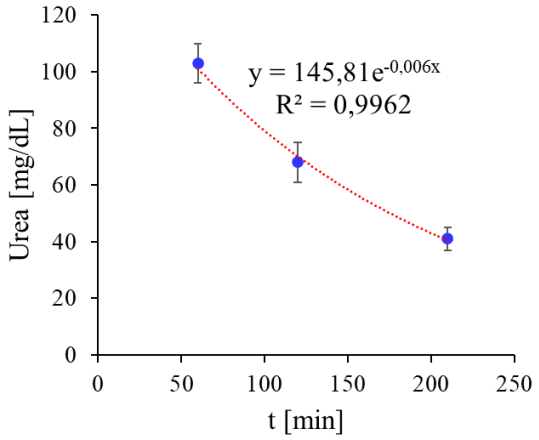
Urea [μM]	Repeatibility RSD%	Reproducibility RSD%	Reproducibility in fabrication* RSD%
25	7	4	20
50	7	7	14
100	4	8	21
300	6	8	15
500	3	7	14

**Calculated on 8 devices measured over 6 days*

HOSPITAL LAB



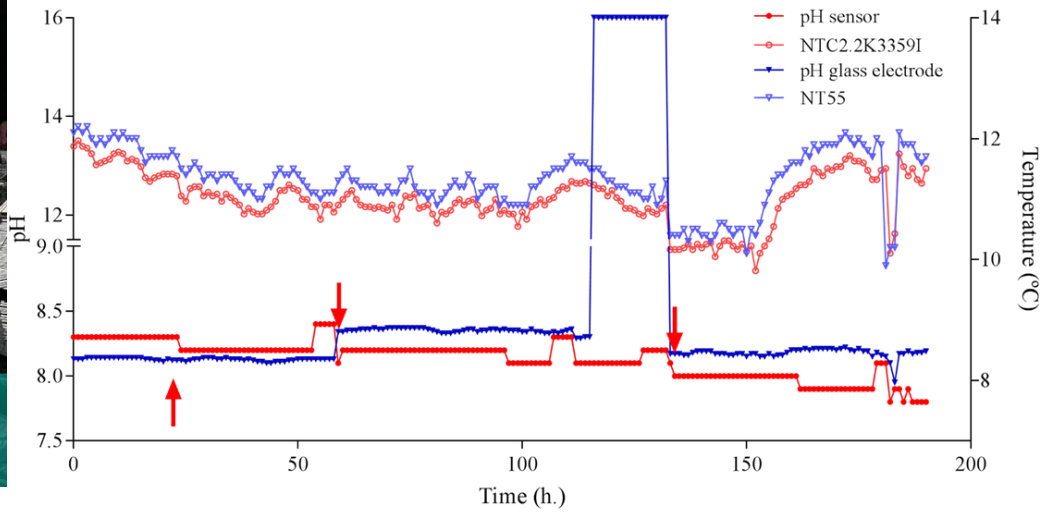
SENSOR

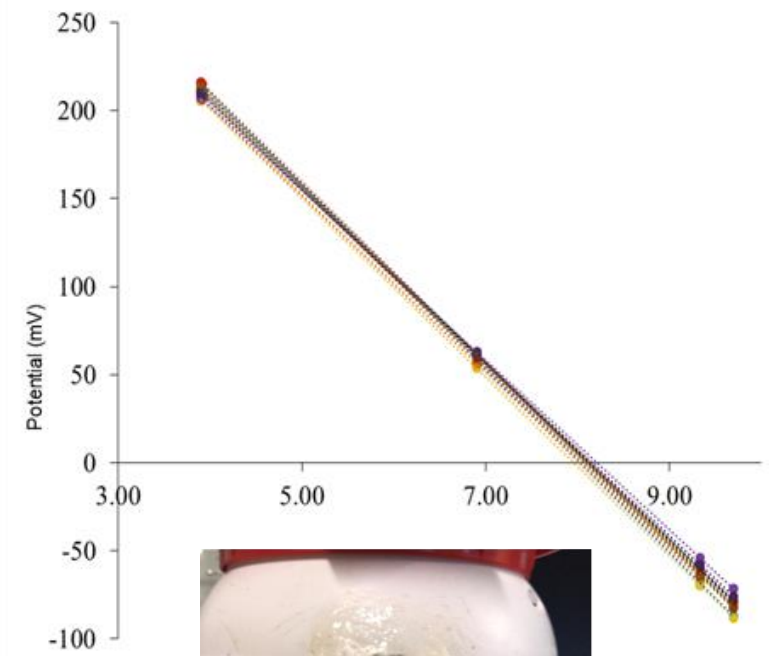


A. Bonini et al. A Graphenic Biosensor for Real-Time Monitoring of Urea during Dialysis, IEEE Sensors Journal 20 (2020) 4571 – 4578.

May artificial intelligence help solving open issues?

- Reproducibility in fabrication
- Reproducibility in measurements
- Chemical interferences and noise
- Biofouling
- Sensor ageing and stability over time





N. Poma et al. Remote monitoring of seawater temperature and pH by low cost sensors, Microchemical Journal 148 (2019) 248-252.

WHAT IS SMART SENSOR ?

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- A sensor producing an electrical output when combined with interfacing electronic circuits is known as “Smart Sensor”.
- It is a combination of both sensor and actuator. [sensor + interfacing circuit = smart sensor]
- Capable of logic functions, two-way communication and making decisions.

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- **Cost improvement**: less hardware and reduction of repetitive testing make smart sensor cost effective.

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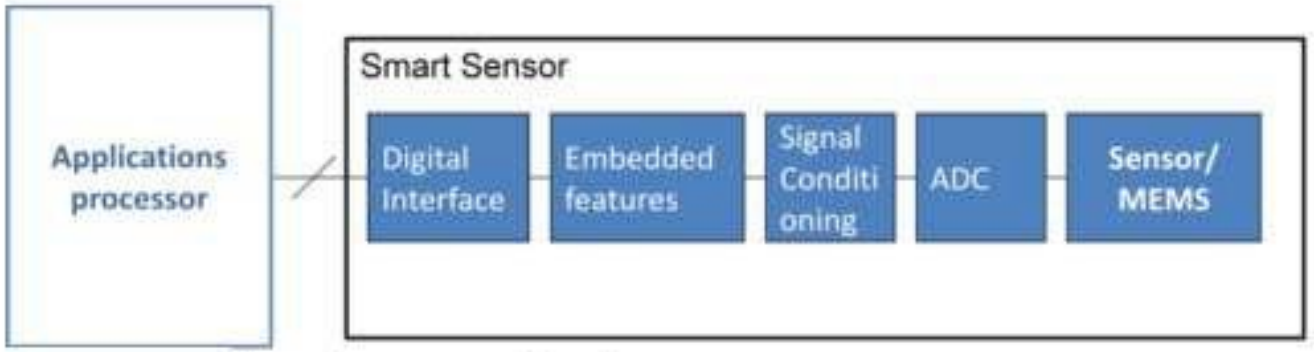
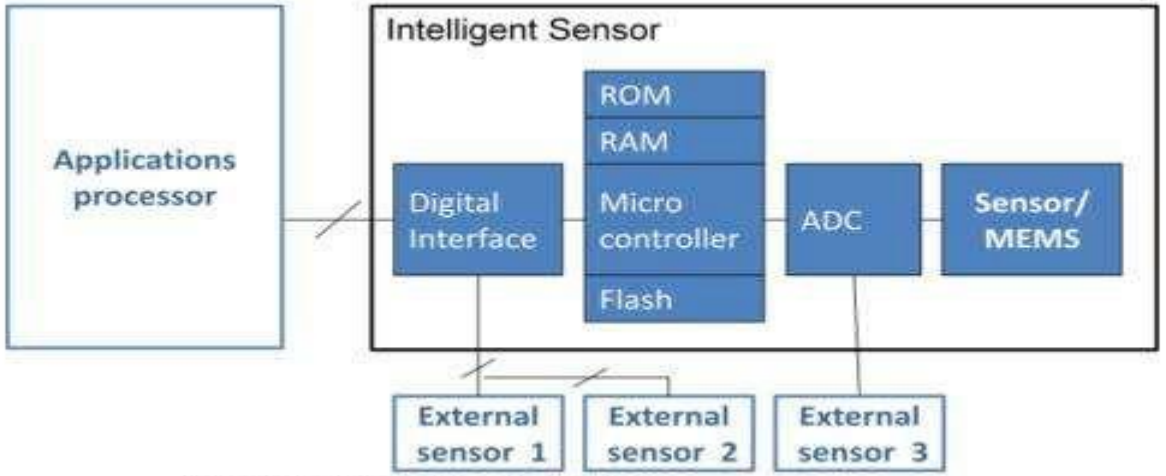
- The main issue of the intelligent sensor is the software partitioning with the applications processor

STRUCTURAL DIFFERENCE

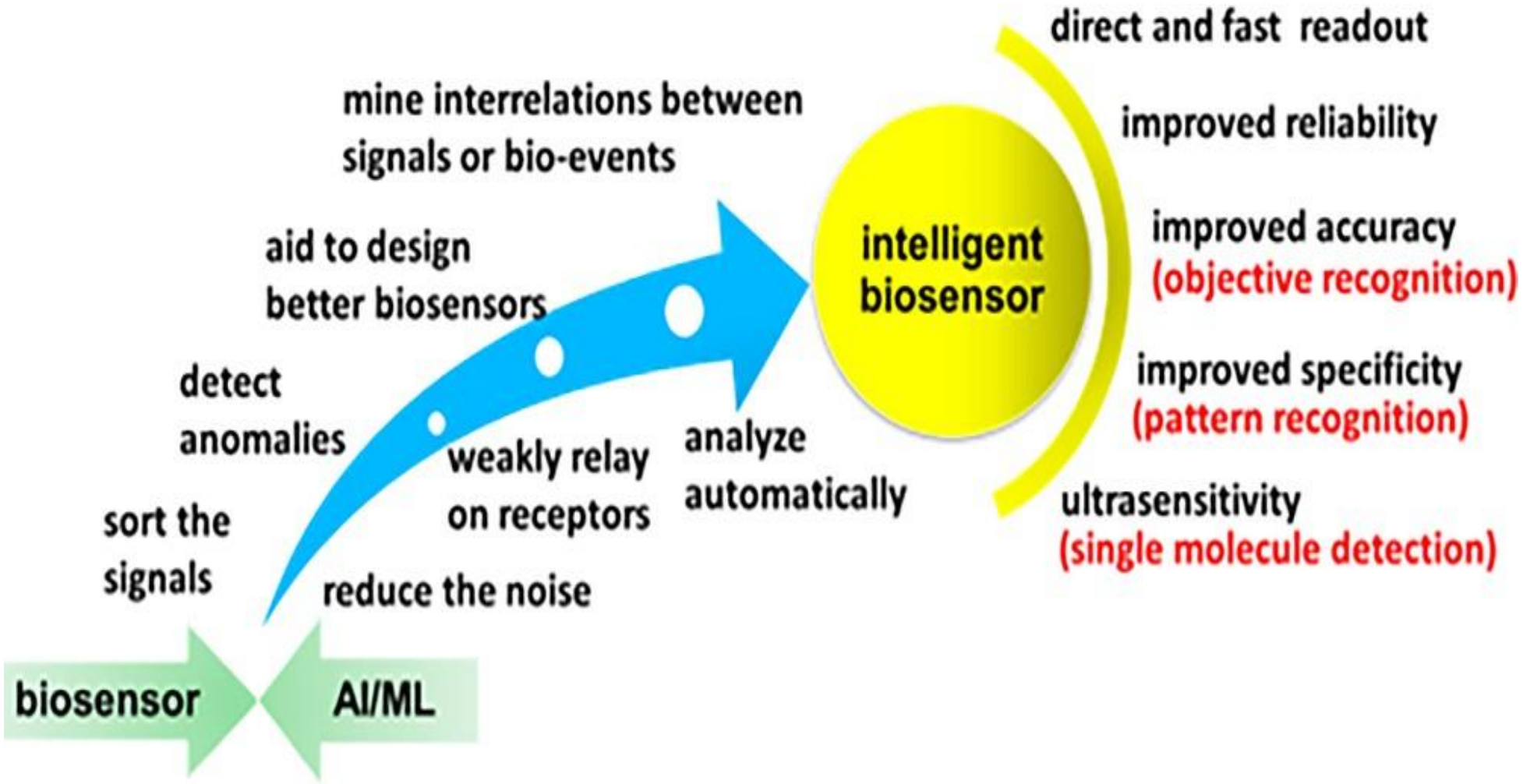


Smart sensor structure

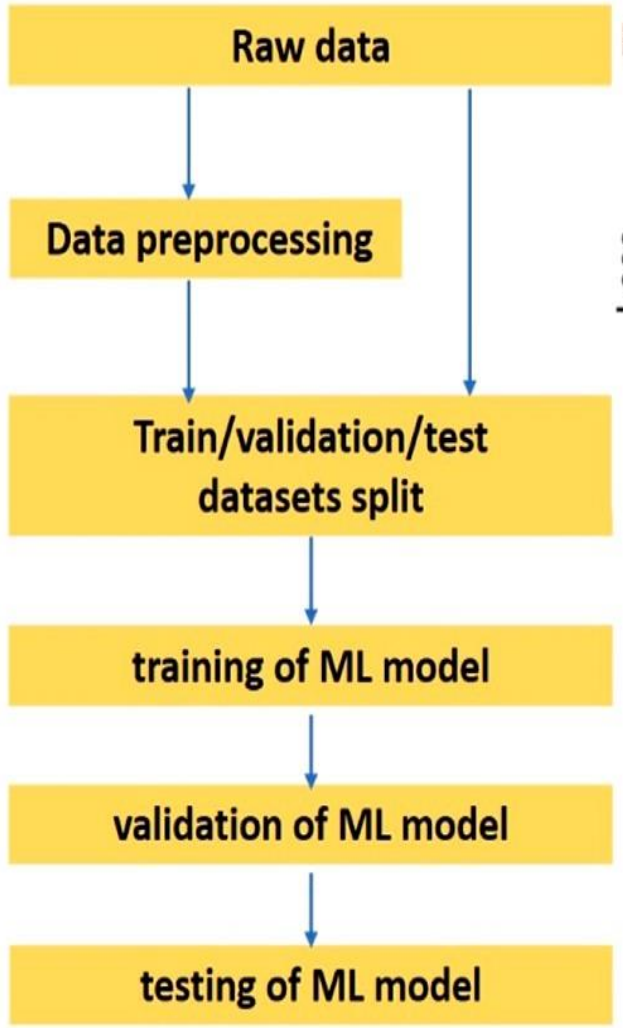


Intelligent sensor structure

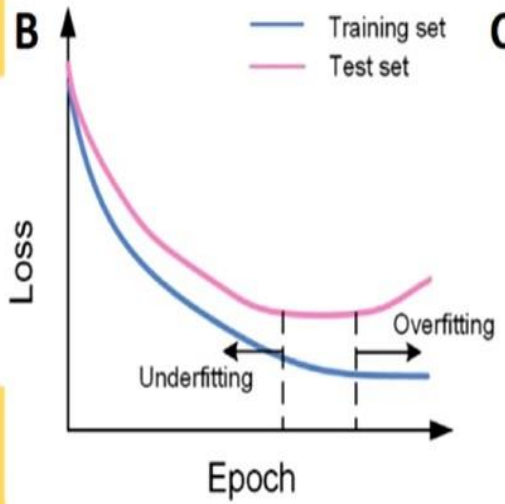
Advancing Biosensors with Machine Learning



A



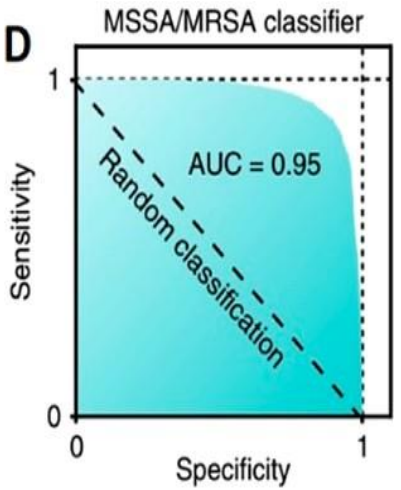
B



C

True Class	Predicted Class: Class 1	Predicted Class: Class 2
Class 1	True Positive (TP)	False Negative (FN)
Class 2	False Positive (FP)	True Negative (TN)

D



C

$$\text{Accuracy} = \frac{TP + TN}{\text{Total}}$$

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall or Sensitivity} = \frac{TP}{TP + FN}$$

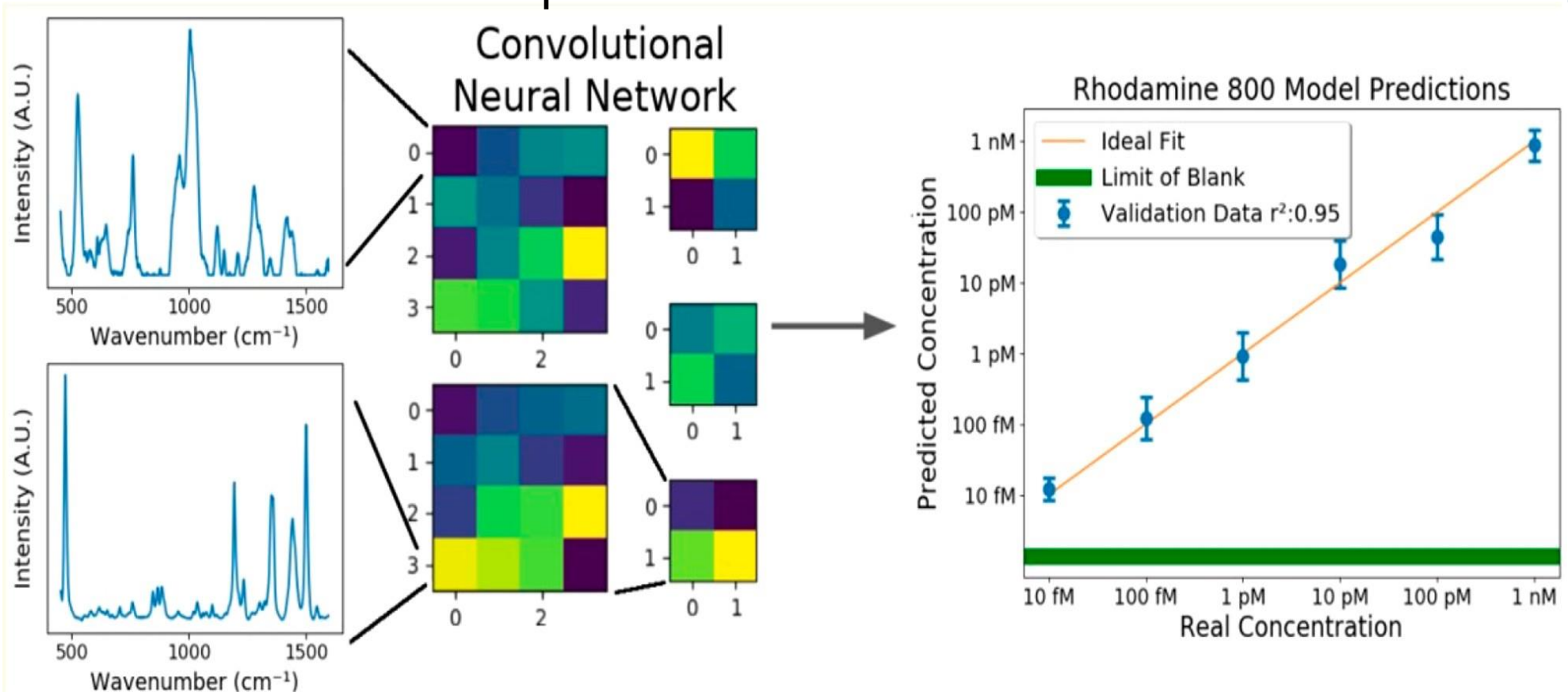
$$\text{Specificity} = \frac{TN}{TN + FP}$$

$$\text{F1 Score} = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

ROC Curve = Sensitivity vs. (1 - Specificity)

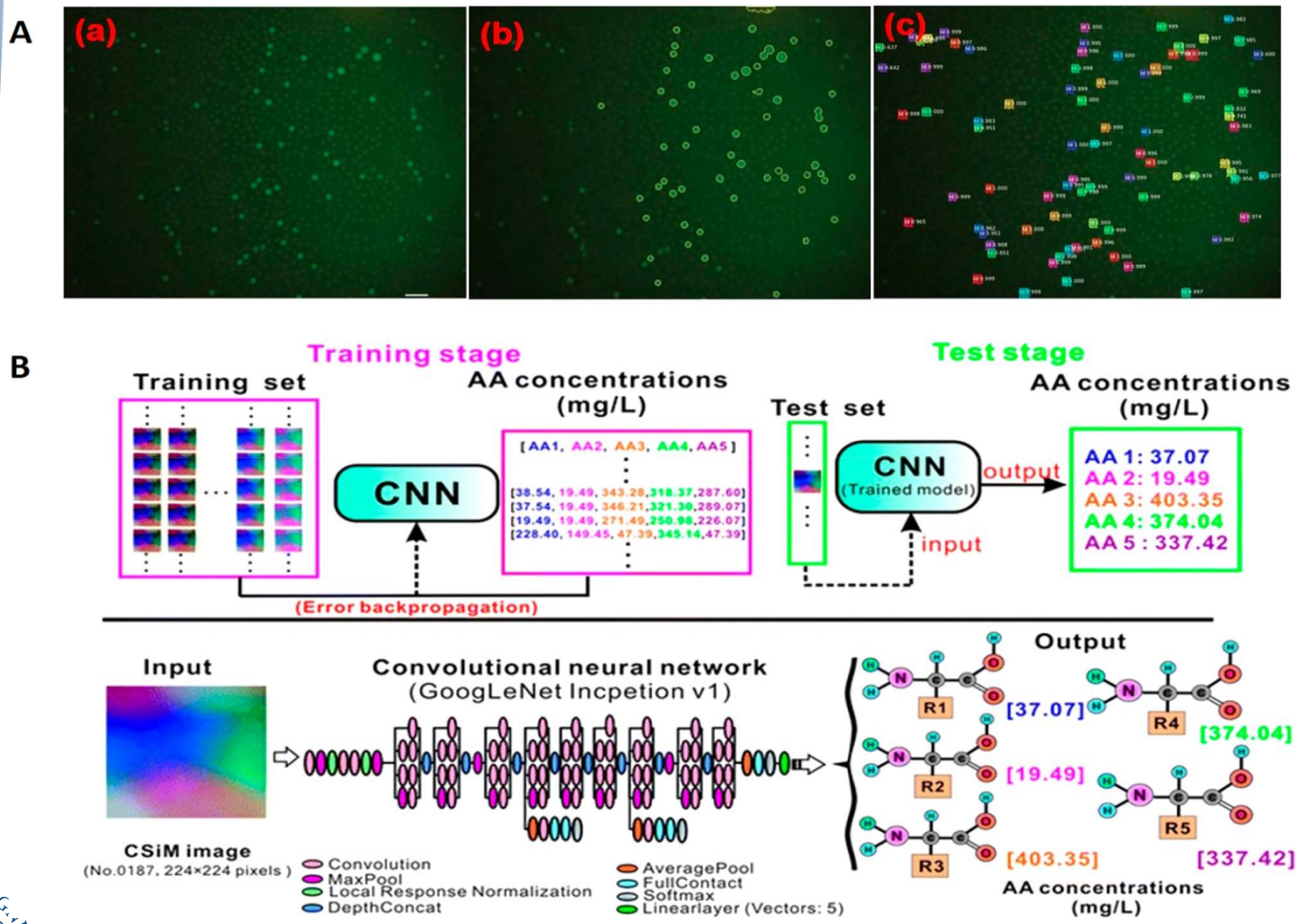
Spectra-Based Biosensors

SERS spectrum of Rhodamine 800



SERS spectrum was converted into pixels which were bundled into pixel maps with the size of 8 × 8, **CNN** model converted spectrum into concentration value.

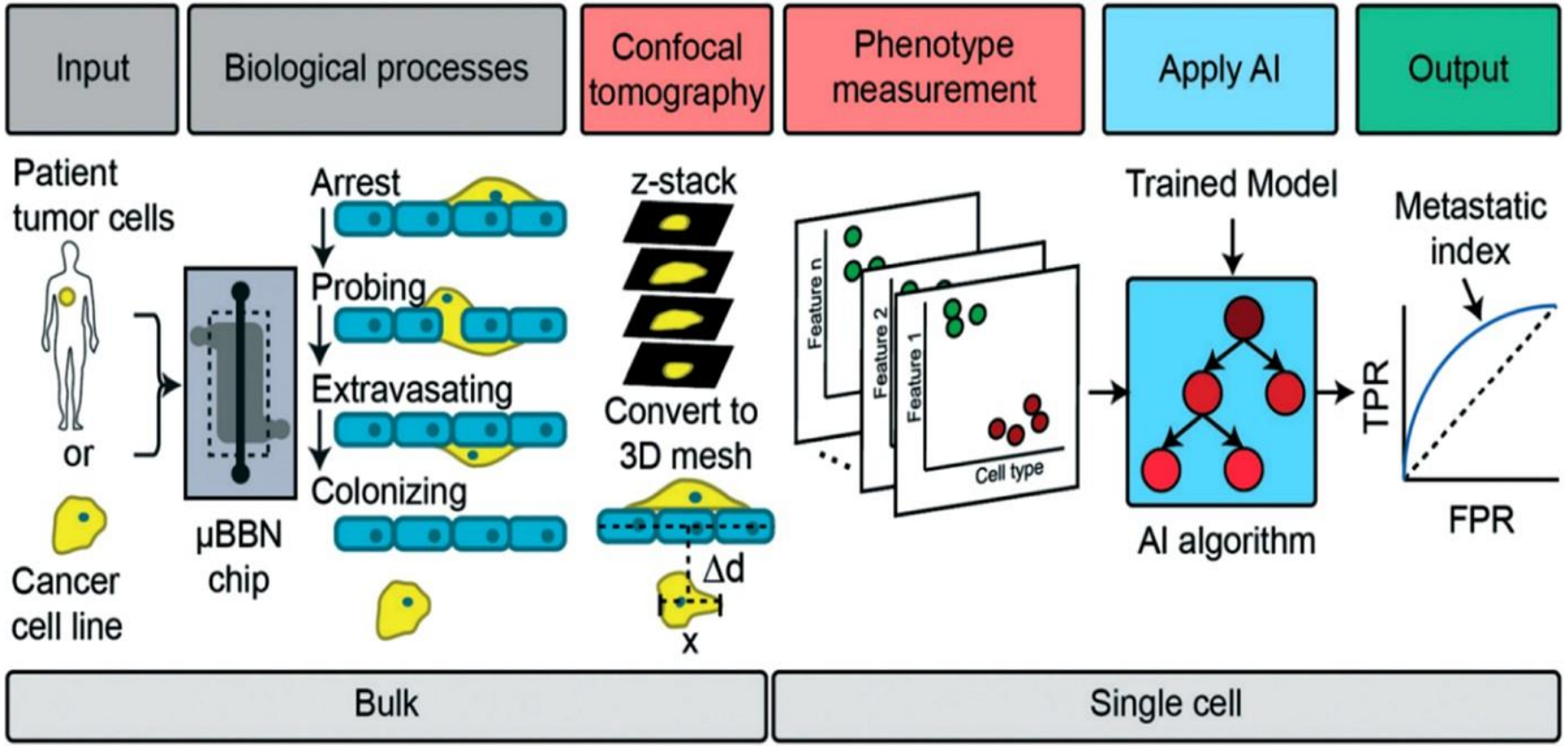
Fluorometric and Colorimetric Biosensors



(A) Analysis of uneven light images by Mask R-CNN model and threshold segmentation.
(a) Image with uneven light from the real experiment.
(b) Results of threshold segmentation.
(c) Results of the Mask R-CNN model.

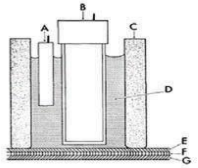
(B) Developed CNN model for mixed AA analysis.

BIOSENSOR NETWORKS AND MULTI-BIOSENSOR DATA FUSION



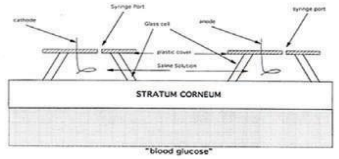
ML-assisted ex vivo blood brain barrier organ-on-a-chip model to investigate brain metastatic spread of cancer

Combined timeline of ML and biosensor



Clark oxygen electrode

1962

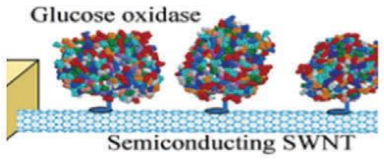


Non-invasive glucose monitoring

Mediated enzyme electrode

1984

1990s

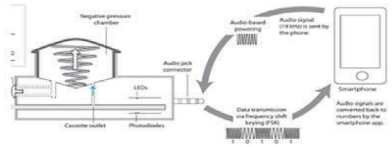


Enzyme-Coated Carbon Nanotubes

2003

Tooth sensor for bacteria detection

2012



Smartphone based diagnosis

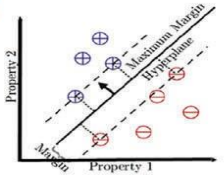
2015

Skin patch for cortisol sensing

2018

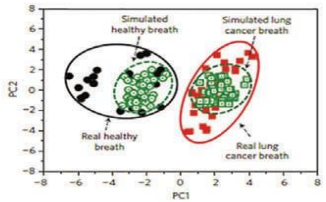
The combination of machine learning and biosensor

2000s



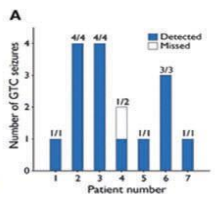
Drug discovery with SVM

2003



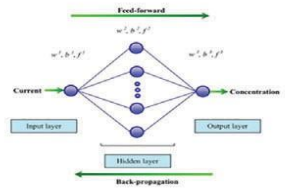
Lung cancer diagnosis with PCA

2009



Convulsive seizure detection with SVM

2012



Catechol detection in water with ANN

2017

1958

Perceptron

1980s

Multilayer Network

1990s

Random Forest, Support Vector Machine, Long short-term memory

2006

Restricted Boltzmann Machine

2012

AlexNet wins ImageNet

2016

AlphaGo

Questions?

Thank you for your attention!

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