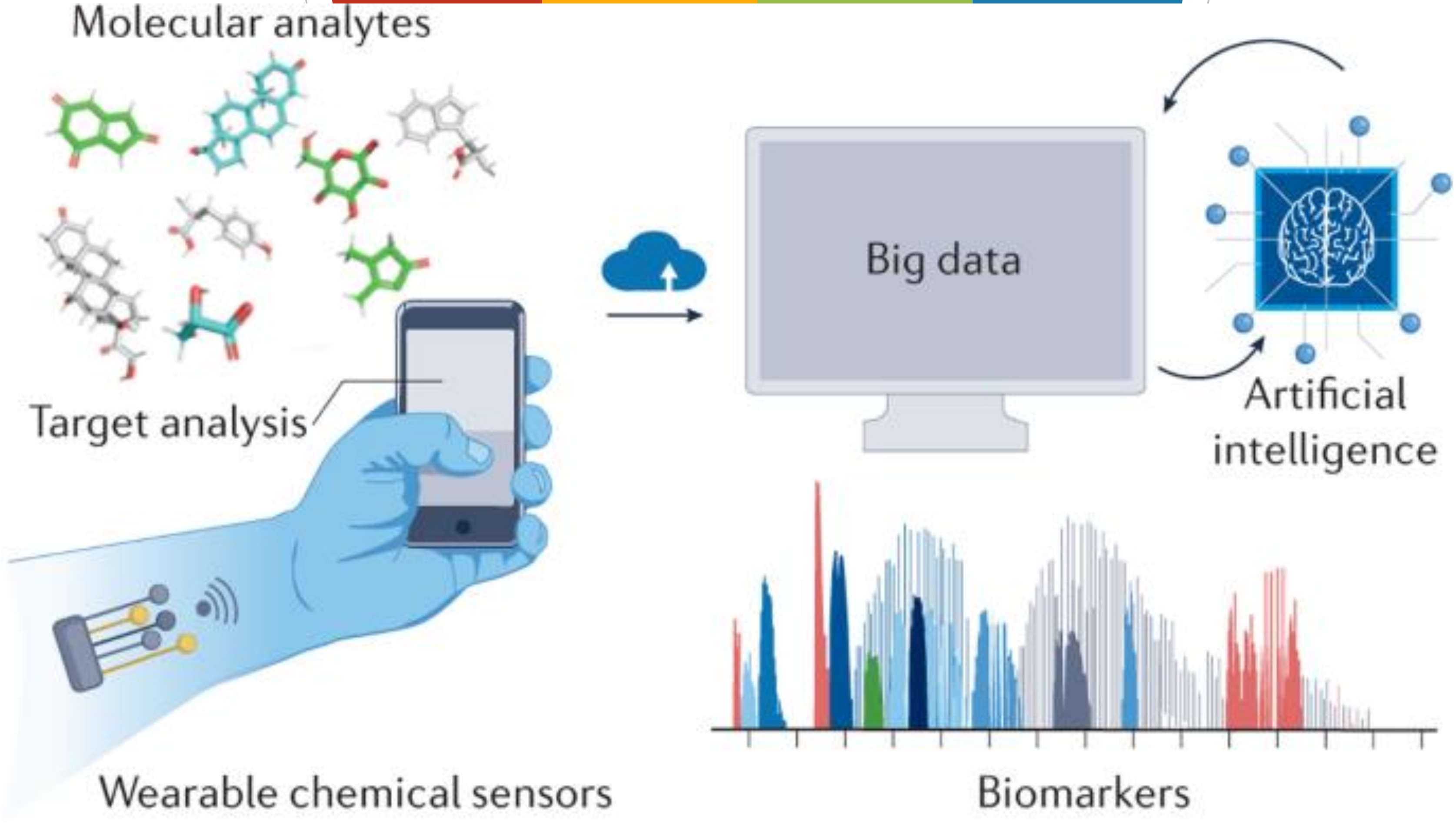
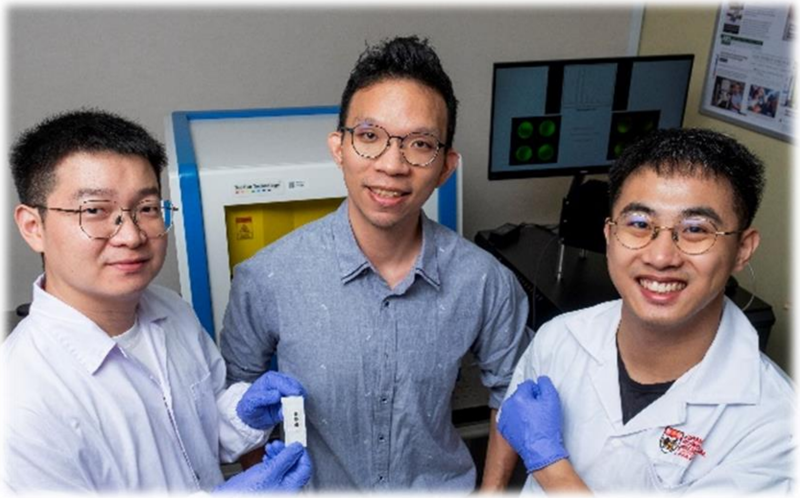
EE 6301
Smart Biosensors and Systems for Healthcare


Molecular analytes
Target analysis
Wearable chemical sensors
Big data
Artificial intelligence
Biomarkers

About Me- From Photonics to Electronics to Biomedicine



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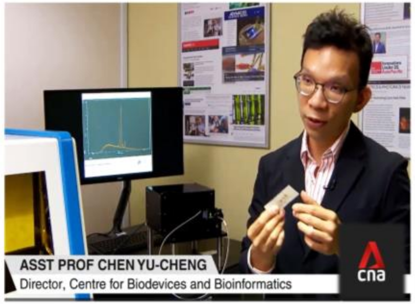
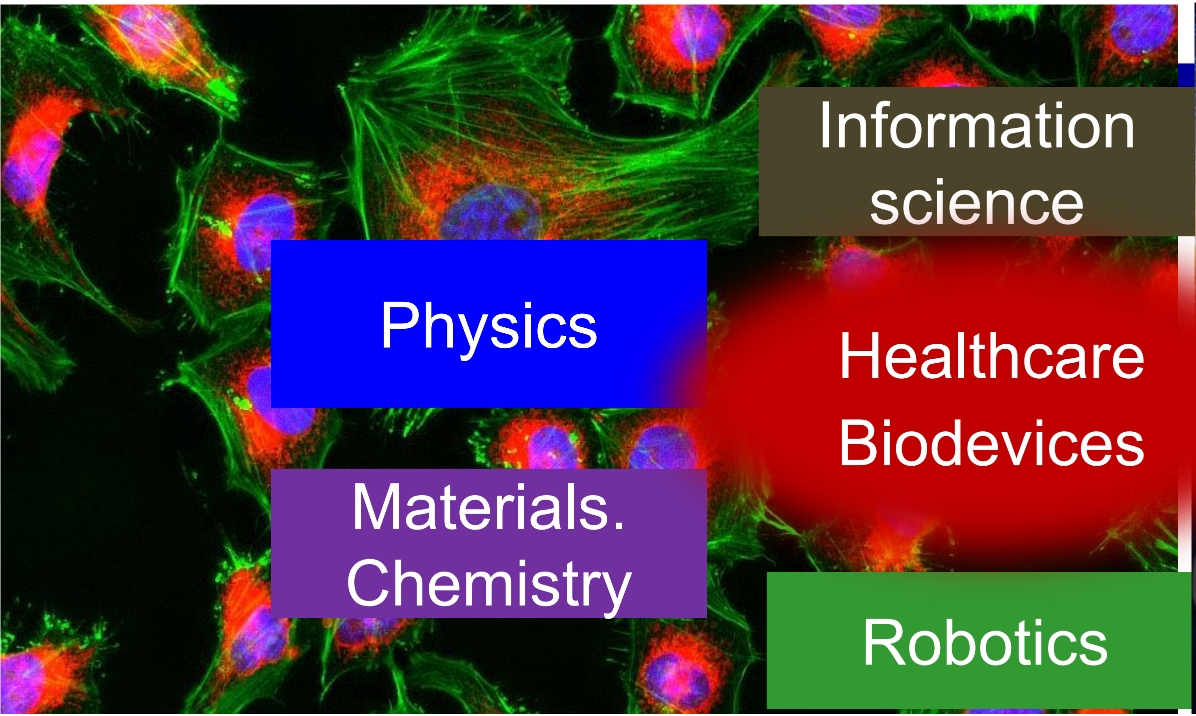
Office: S1 B1A-26

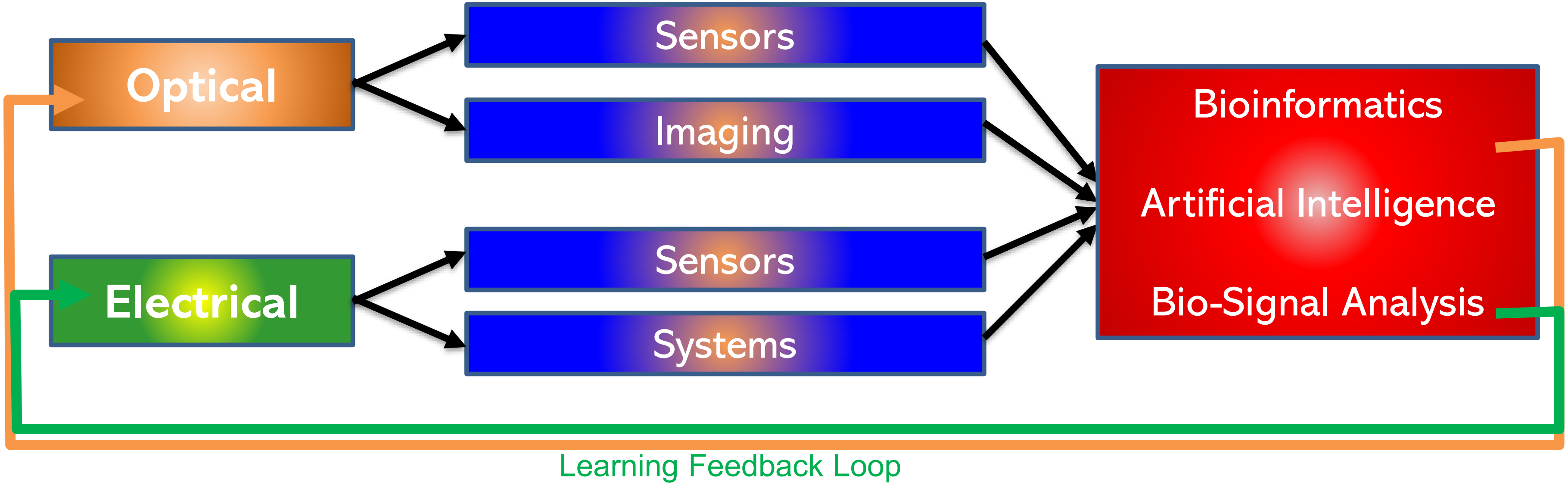


MIT Technology Review
Innovators Under 35



Healthcare is human-oriented, we will always need new technology for diagnosis and monitoring.

Course Structure and Aims



- **Learn fundamental principles of optical and electrical based sensors.**
- **Learn the applications and functions of optical/electrical biomedical sensors.**
- **Realize how AI can play a key role in healthcare industry and research to solve or improve current sensors.**

Learning Blocks

Optical biosensors (9 hours)

- Fundamentals & principles of biosensors (3) light properties and optical biosensor (3)
- Major types of optical sensors (3)
- Applications of optical biosensors in medicine (3)

Imaging systems (9 hours)

- Fundamentals of imaging and analysis (3)
- Various types of optical imaging systems
- Imaging system for disease diagnosis in medicine (3)
- Digital Health and Digital Care (3)

Team Learning 6 hrs

Electrical biosensors (6 hours)

- Fundamentals, principles, and fabrication of electrical biosensors/ bioelectronics (6)
- Applications of wearable sensors/ human-machine interface (3)

Bio-Intelligent systems AI in healthcare (9 hours)

- Biochip, medical system, and smart healthcare devices (3)
- Robotics and AI (3)
- Artificial intelligence in medical sensing and imaging (3)

Learning Outcomes

Biomedical Sensors & Healthcare devices

- Fully understand the science and working principle of optical and electrical biosensors and imaging systems.
- **What are the technological needs in real world medicine?**

Bio-information science & Artificial Intelligence

- Understand what are tools in AI that can be applied to healthcare?
- What are AI opportunities in new medicine?
- **Know how to apply AI into healthcare technologies and diagnosis.**

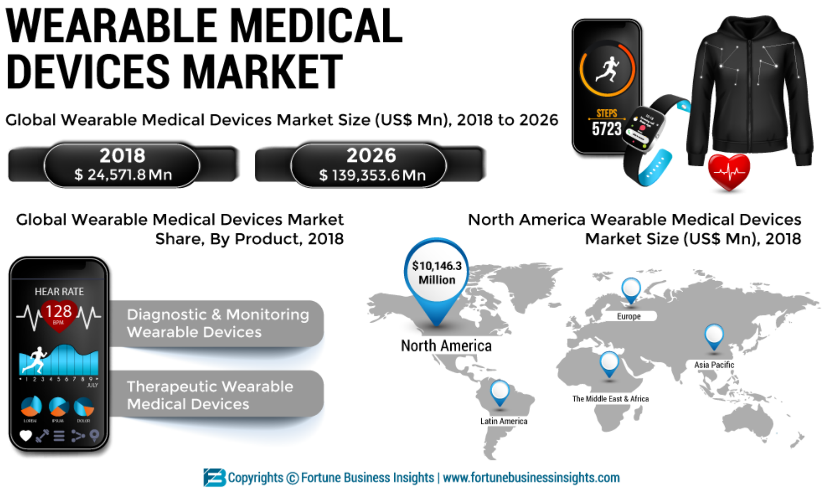
Future Development & Impact

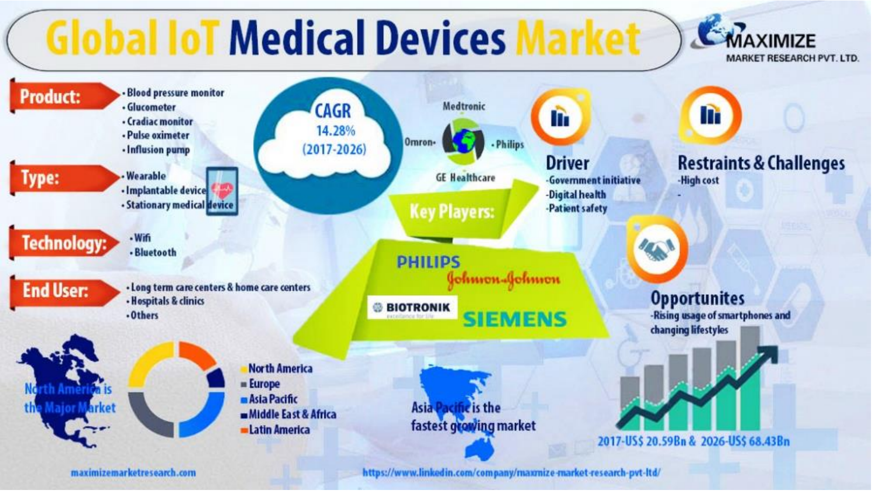
For PhD/MEng students

- Smart medical devices research
- Biomedical signal analysis

For Undergrad/ MSc students

- Healthcare device development
- AI / IoT healthcare industry





Evaluation Matrix

Quiz (20%)	Quiz 1 : MCQ (about 50 minutes) Quiz 2 : MCQ (about 50 minutes)
Final Examination (60%)	Covering most of the topics in the lecture.
Project + Presentation (20%)	1 student per project. Selected topic for a mini proposal (Fixed Topic) 5-7 minutes (recorded and uploaded slides online)

Schedule (2025-26 Sem2)

Week	Topic
1	Introduction to biosensors and AI in modern healthcare
2	Optical biosensors (I)- Basic fundamentals of photonic sensing
3	Optical biosensors (II)- Structure and applications of photonic biosensing
4	Biomedical imaging technologies (I)
5	Biomedical imaging technologies (II)
6	Chinese New Year
7	Introduction to electrical biosensors (I)- Electrochemical Biosensors
	RECESS WEEK
8	Introduction to electrical biosensors (II)- Bioelectronics and Biopotentials
9	Bioelectronic devices and systems + **Quiz 1**
10	Digital health and Digital Pathology: Future healthcare systems
11	Artificial intelligence and multi-scale AI for medicine (Prof. Huang Hen Wei)
12	Opportunities and challenges of Robotics in clinical medicine (Prof. Huang Hen Wei)
13	System packing and encapsulation of bioelectronics (Prof. Huang Hen Wei) + **QUIZ 2**
	FINAL PROJECT DUE FINAL EXAM

EE6301 Week 1- Introduction to Biosensors and Modern Healthcare

Professor Chen Yu-Cheng

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2025 Fall

CONTENT

1

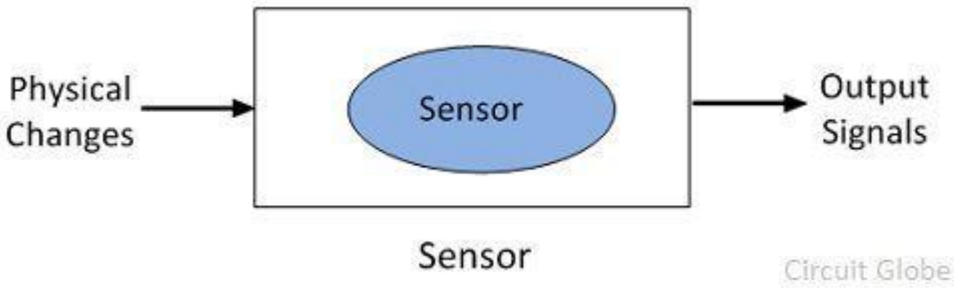
PART ONE

Background of Sensors

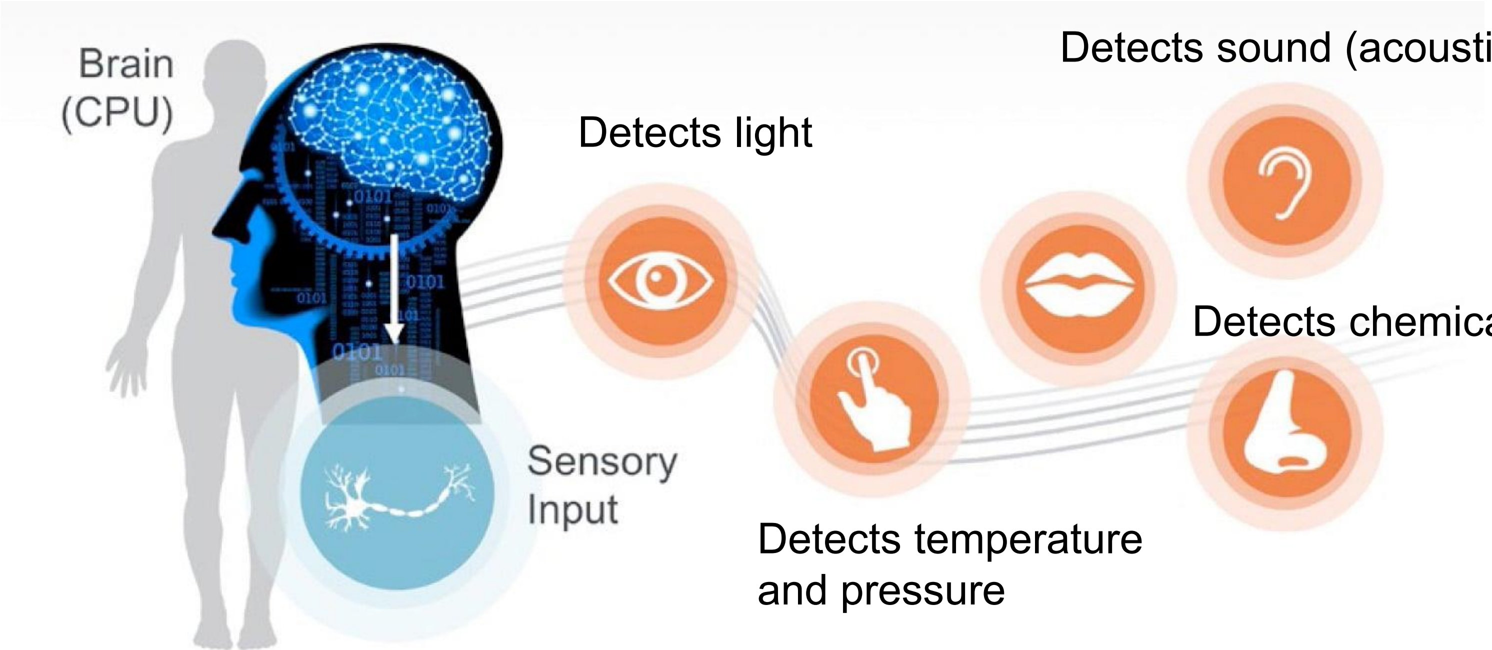
What is a Sensor?

A sensor is a device that detects and responds to input (stimulus) from its physical environment.

- The input can be any physical quantity like pressure, force, strain, light etc., can be identified and converted into an useful signal.
- A sensor converts the signals into an analog or digital representation of input signals.
- Sensors can detect or quantify many different conditions.



What are some sensors on your body?



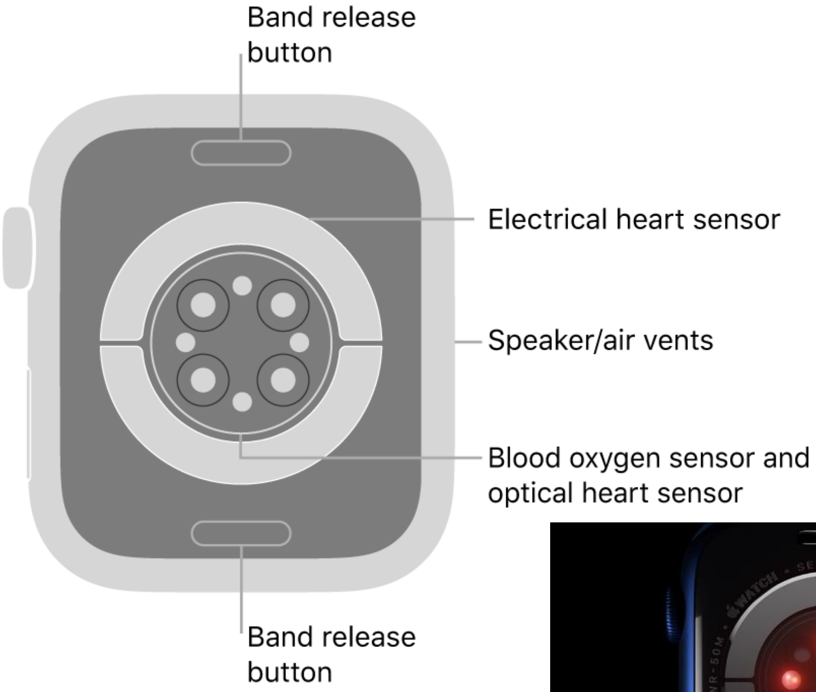
Detects light

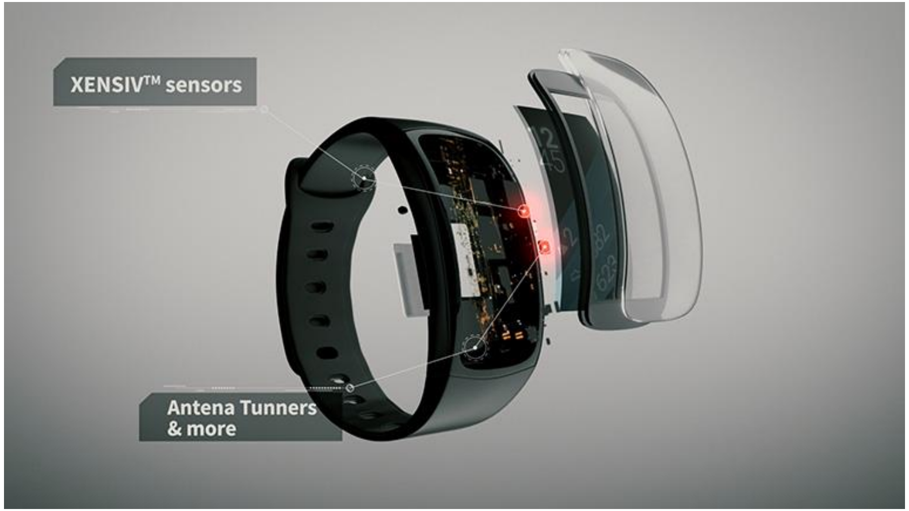
Detects sound (acoustic signal)

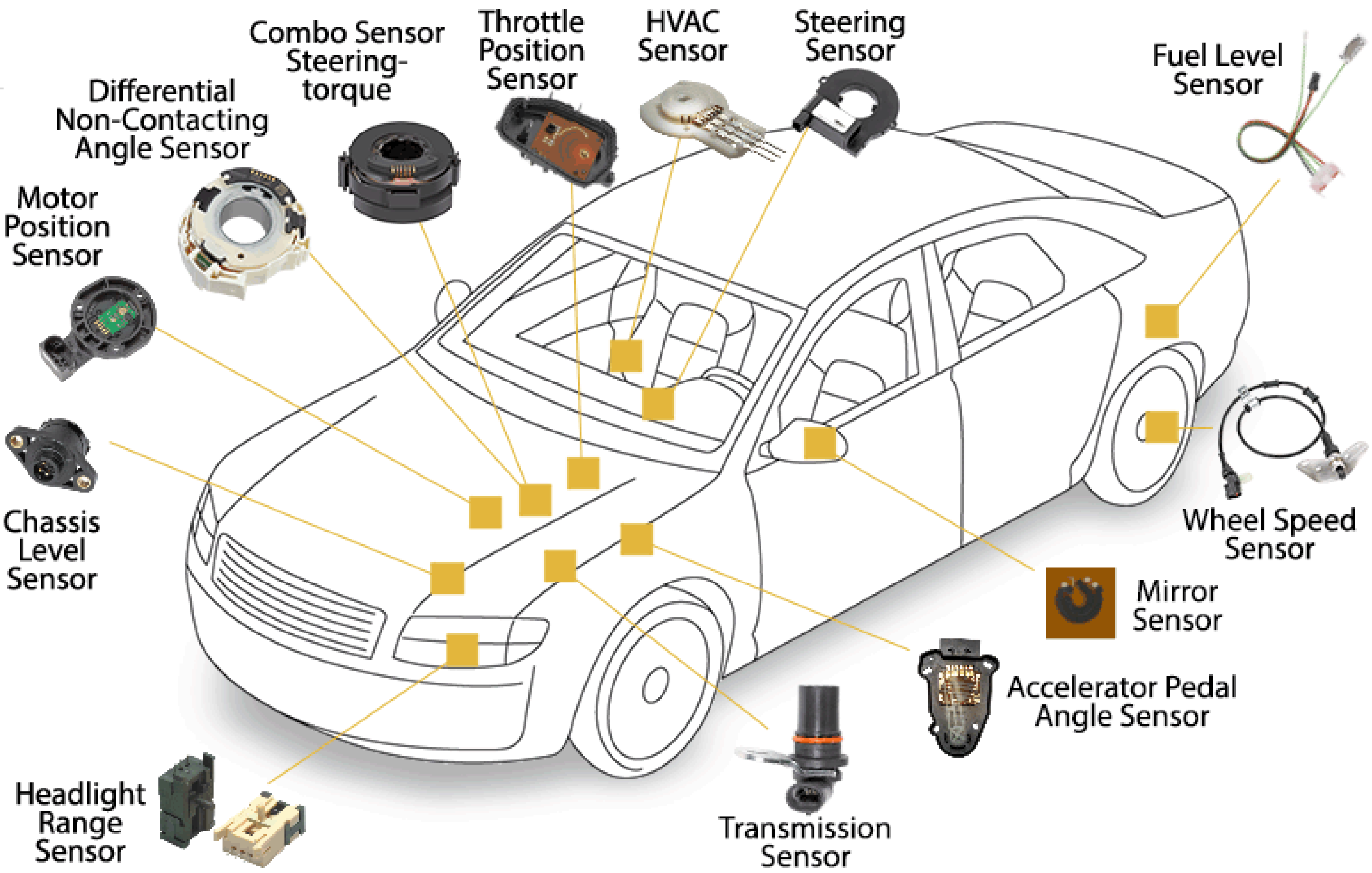
Detects chemical signals

Detects temperature
and pressure

What are some sensors you wear?



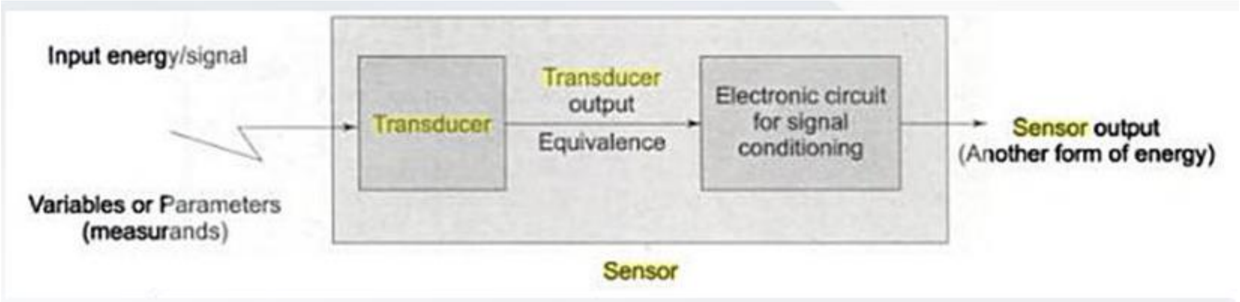



Combo Sensor Steering-torque
Throttle Position Sensor
HVAC Sensor
Steering Sensor
Fuel Level Sensor
Differential Non-Contacting Angle Sensor
Motor Position Sensor
Chassis Level Sensor
Wheel Speed Sensor
Mirror Sensor
Accelerator Pedal Angle Sensor
Headlight Range Sensor
Transmission Sensor

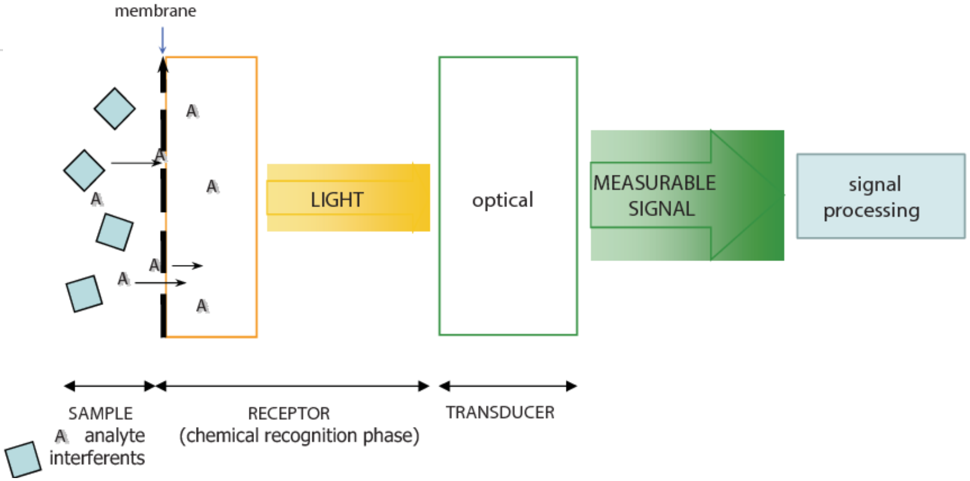
What is a Transducer ?

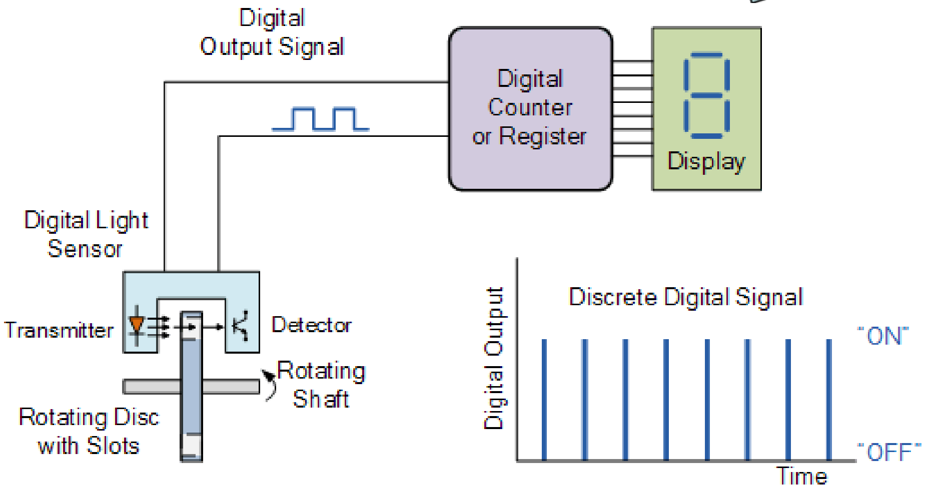
A transducer is a more general device for converting energy from a given form into a different form.
Transducer that turns one form — physical, chemical or biological — into a specific different form (electronic data).

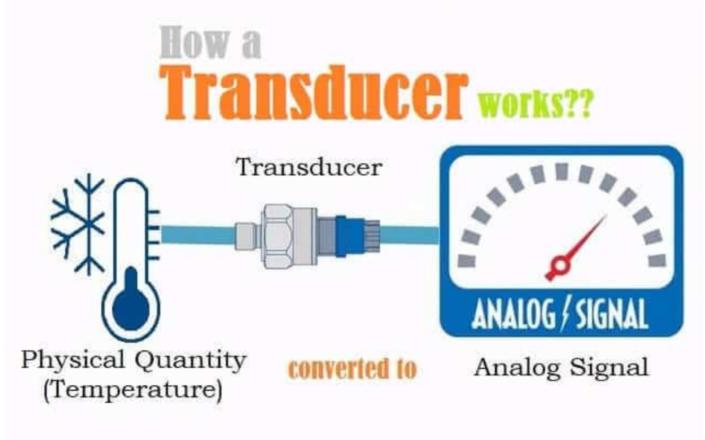
A sensor is more of a detector to obtain data, while a transducer is more of a translator which translates into readable information



What is a Transducer ?







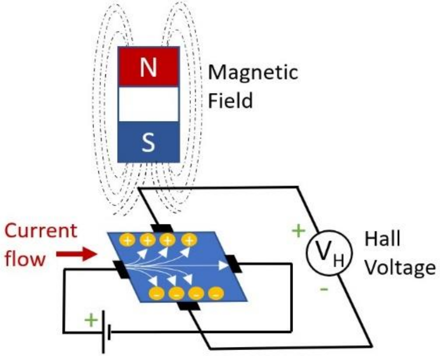
Types of Sensor

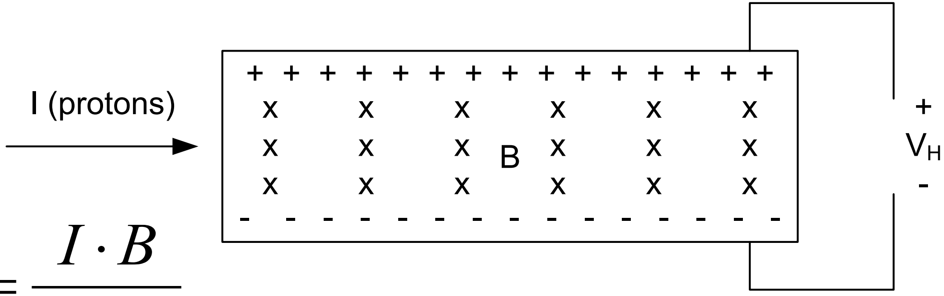
Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Magnetic Sensors

- Magnetic Field sensors are used for power steering, security, and current measurements on transmission lines

- Hall voltage is proportional to magnetic field

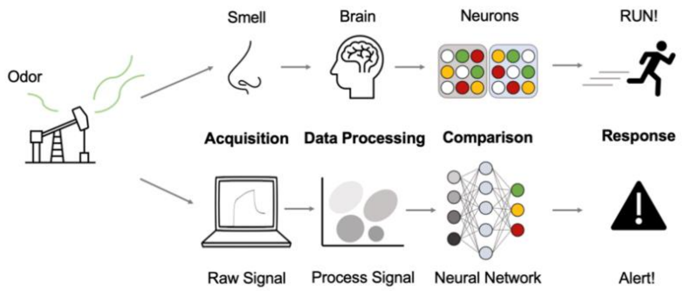


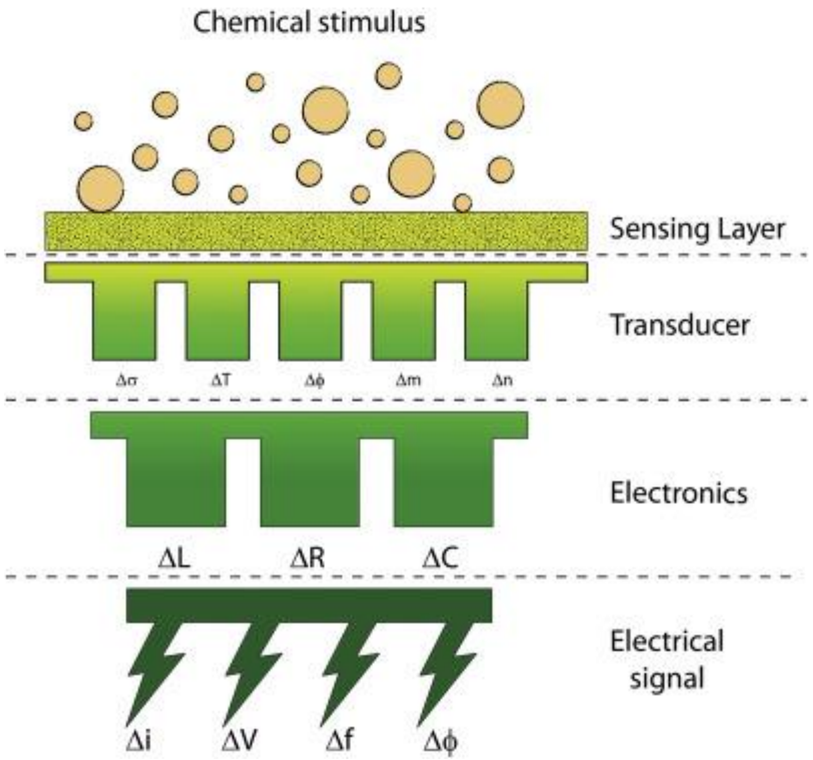


$$V_H = \frac{I \cdot B}{n \cdot q \cdot t}$$

Chemical Sensors

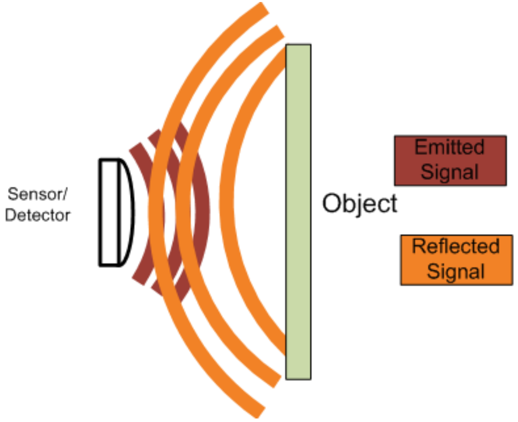
A chemical sensor is an analyzer that responds to a particular analyte in a selective and reversible way and transforms input chemical quantity, ranging from the concentration of a specific sample component to a total composition analysis, into an analytically electrical signal

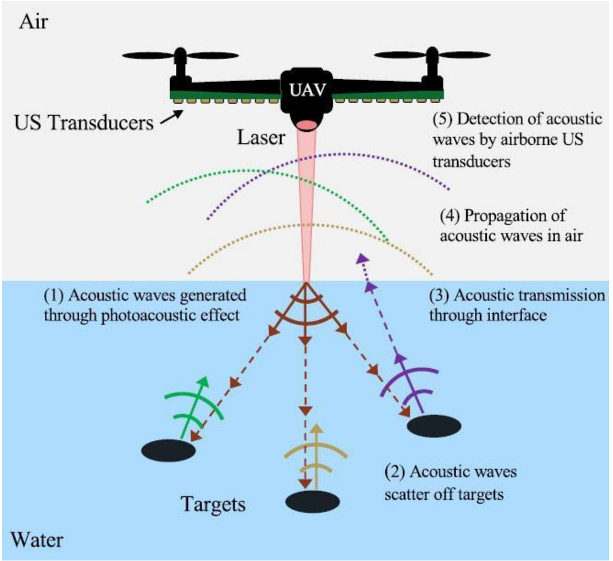




Acoustic Sensors

- Ultrasonic sensors are used for position measurements
- Sound waves emitted are in the range of 2-13 MHz
- **So**und **N**avigation **A**nd **R**anging (SONAR)
- **Ra**dio **D**ection **A**nd **R**anging (RADAR) – ELECTROMAGNETIC WAVES !!

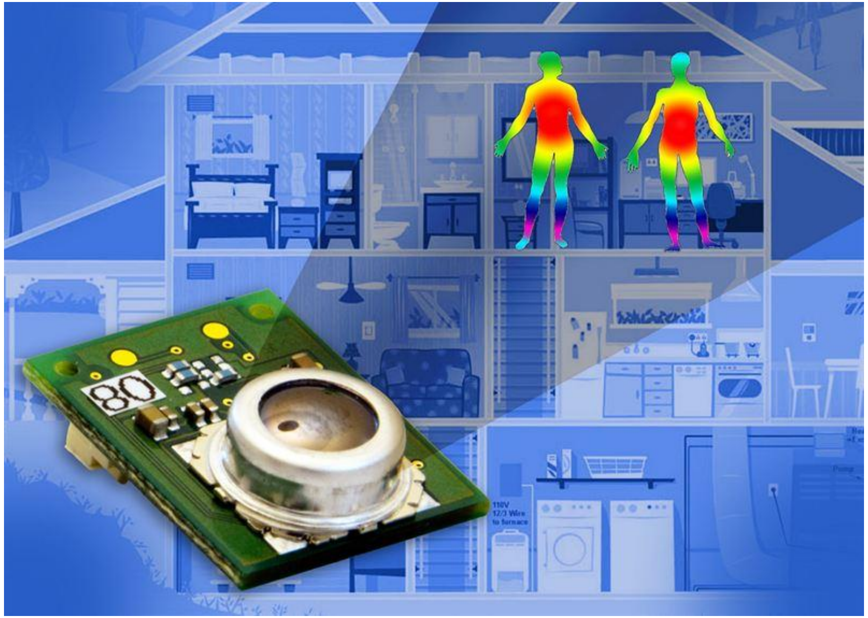




Thermal Sensors

- Temperature sensors appear in building, chemical process plants, engines, appliances, computers, and many other devices that require temperature monitoring

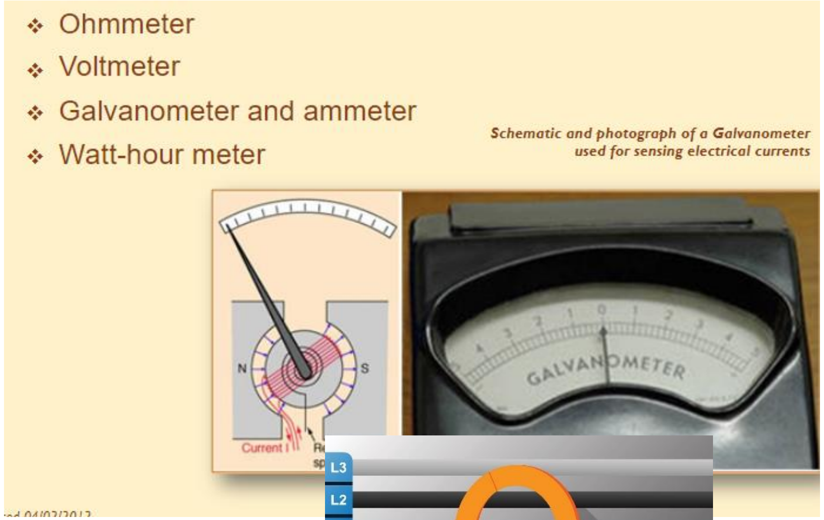
- Many physical phenomena depend on temperature, so we can often measure temperature indirectly by measuring pressure, volume, electrical resistance, and strain



Electrical Sensors

- Electrical Sensors/Detectors/Transducers are electronic devices that sense current, voltage, etc. and provide signals to the inputs of control devices or visual displays.

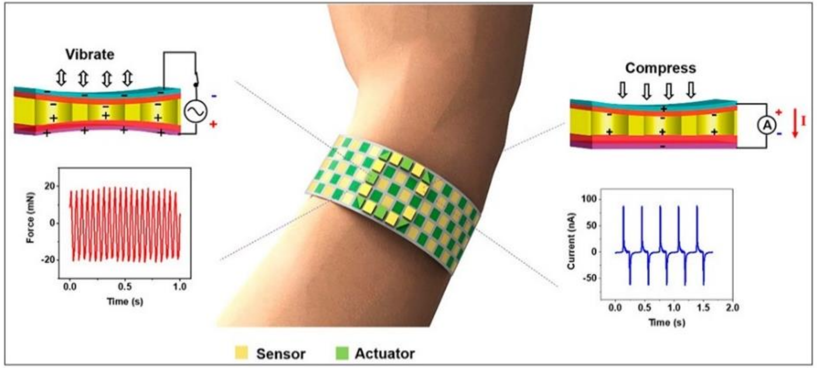
- Current_sensors are important control components of power electronic systems such as frequency converters, traction converters, UPS systems, and welding systems.

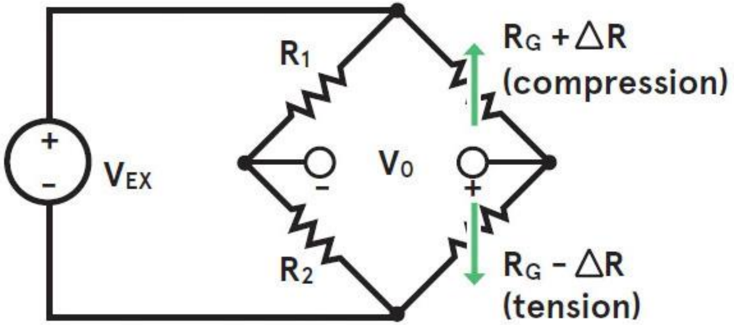


Mechanical Sensors

- Pressure sensors are instruments or devices that translate the magnitude of the physical pressure that is being exerted on the sensor into an output signal that can be used to establish a quantitative value for the pressure.

- Force sensors, are devices that are designed to translate applied mechanical forces, such as tensile and compressive forces, into output signals whose value can be used to reflect the magnitude of the force.

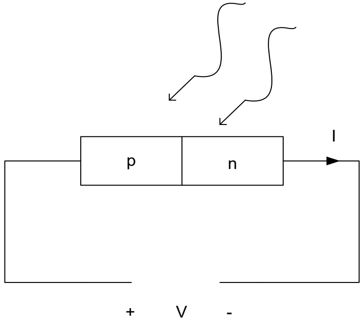


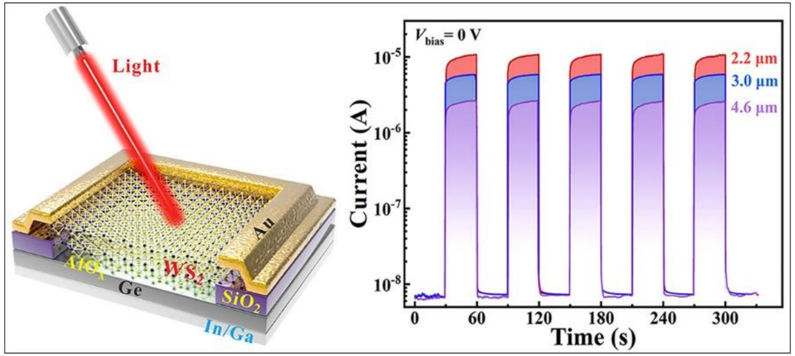


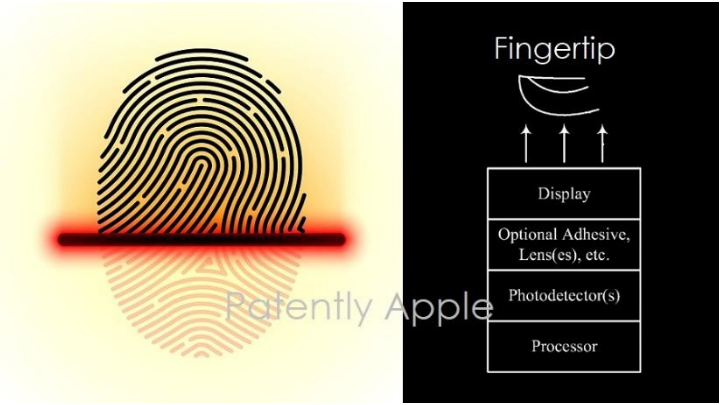
https://www.thomasnet.com/articles/instruments-controls/pressure-sensors/

Light Sensors

- Optical sensors are those sensors that detect electromagnetic radiation in the broad optical range – from far infrared to ultraviolet
- Photoelectric effect is ones of the commonly used principle- due to the change of conductivity or electron mobility.
- Sensor is composed of photoconductor such as photodiode
- Infrared sensors, solar cells, proximity sensors

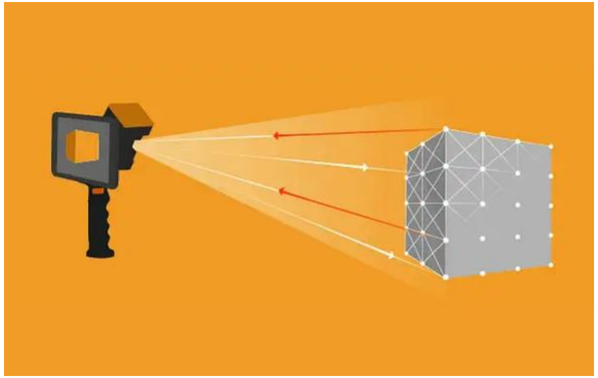






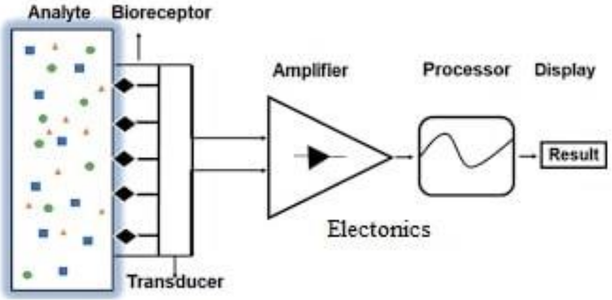
LiDAR Sensors

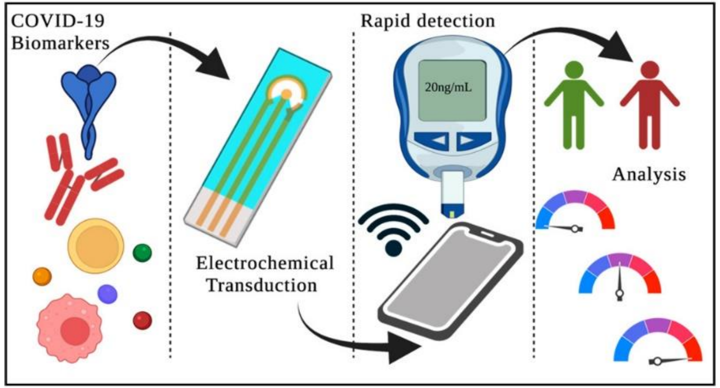
- LiDAR is a remote sensing method. LiDAR technology uses the light from a laser to collect measurements. These are used to create 3D models and maps of objects and environments.
- A LiDAR system calculates how long it takes for beams of light to hit an object or surface and reflect back to the laser scanner. The distance is then calculated using the velocity of light
- Lidar sensors are a key component in autonomous vehicles, **providing a high-resolution 3D view of their surroundings**. Lidar enables autonomous vehicles to “see” by generating and measuring millions of data points in real time

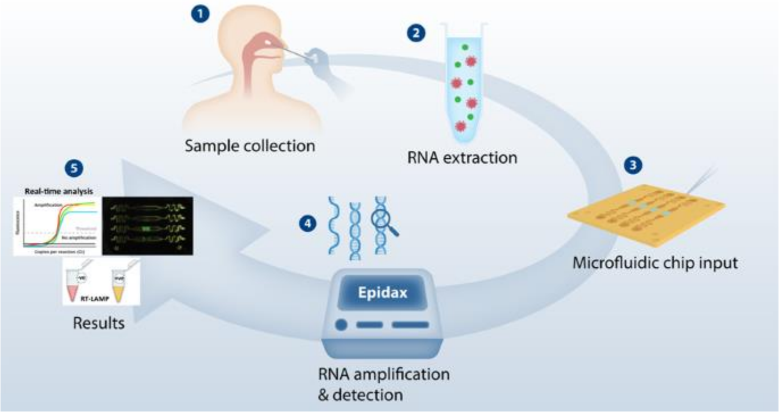


Biological Sensors

- Biosensor is **a device that consists of two main parts: bioreceptor + transducer**.
- Bioreceptor is a biological component that recognizes the target analyte.
- Transducer is a physicochemical detector component that converts the recognition event into a measurable signal.

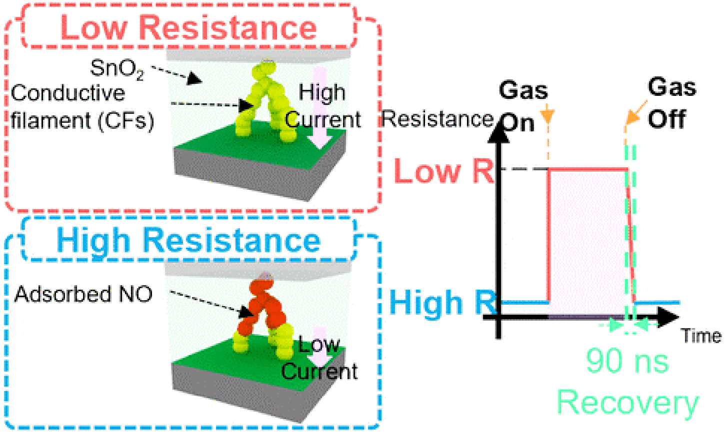


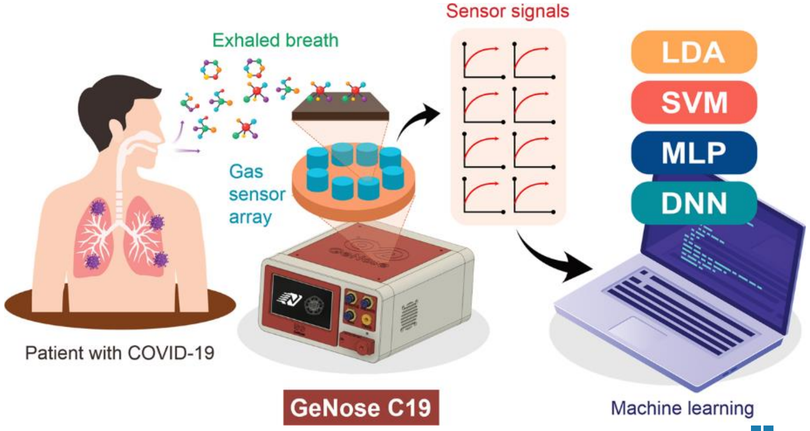




Gas Sensors

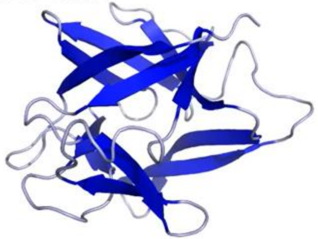
- Gas sensors are devices that help us understand the amount of gas in the environment and the natural state of its movement.
- Gas sensors reveal the amount of gas in the environment and the nature of the gas composition with electrical/optical signals and can provide its change





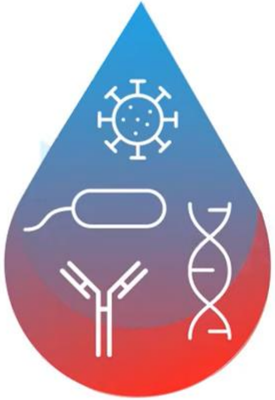
Sensors for wide range of applications

Life Sciences



Pharma

Diagnostics



Samples to detect:

- Small molecules (i.e. drugs)
- Biomolecules (i.e. proteins, antibodies)
- Nucleic acids (DNA, RNA, miRNA)
- Extracellular vesicles (exosomes)
- Pathogens (virus, bacteria)
- Cells ....

Enviromental

Food Safety

Security

https://upload.wikimedia.org/wikipedia/commons/6/60/IL1b_Crystal_Structure.png

https://www.contractpharma.com/issues/2017-03-01/view_features/modeling-simulation-for-drug-development-formulation/

https://www.gettyimages.ch/detail/foto/infrared-television-display-lizenzfreies-bild/1150080006?adppopup=true

https://www.prescouter.com/2018/01/non-invasive-biosensing-companies-2018/

https://primefeed.in/news/4470654/global-environmental-monitoring-sensors-market-2020-competitive-analysis-a

2

PART TWO

Introduction to Biosensors

Biosensor

Long lines to get a PCR analysis…..

Long times to get a PCR result…..

Centralized Diagnostics

Biosensor

Based on symptomatology + **clinical analysis of samples in centralized laboratories**

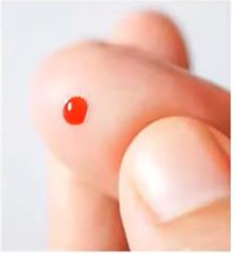
- **WAITING FOR DIAGNOSTICS**
  From hours to days
- **LATE DRUG ADMINISTRATION**
  Major problem in emergencies
- **INEFFICIENT POPULATION SCREENING**
  Too expensive, need of a lab

Laboratory Techniques →

- **Time consuming**
- **High Sample volume**
- **Trained personnel**
- **Laboratory installations**
- **Bulky/expensive instrumentation**

Centralized Diagnostics

POINT-OF-CARE Biosensor technology for decentralized diagnostics



Drop of sample

Point-of-care (POC) device

Pesonalised Treatment

BIOSENSORS provide the possibility to create **POINT-OF-CARE** devices containing the functionalities of an analytical laboratory

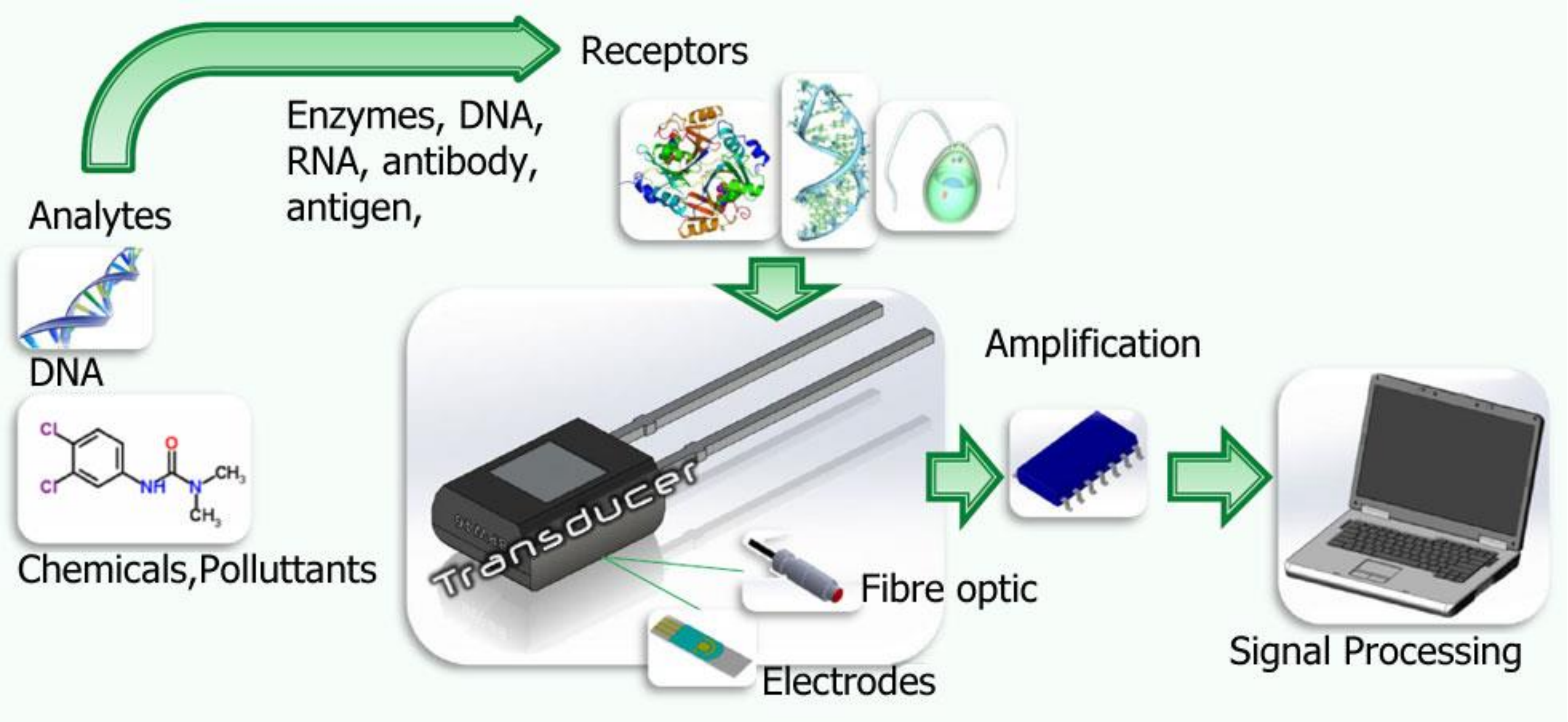
- **Easy diagnostics**
- **High sensitivity and Fast**
- **Reliability and Quantitative**
- **Multiplexing capabilities**
- **User-friendly/minimum operation**
- **Minimum sample, Competitive cost**

Point-of-Care (POC) diagnostics will

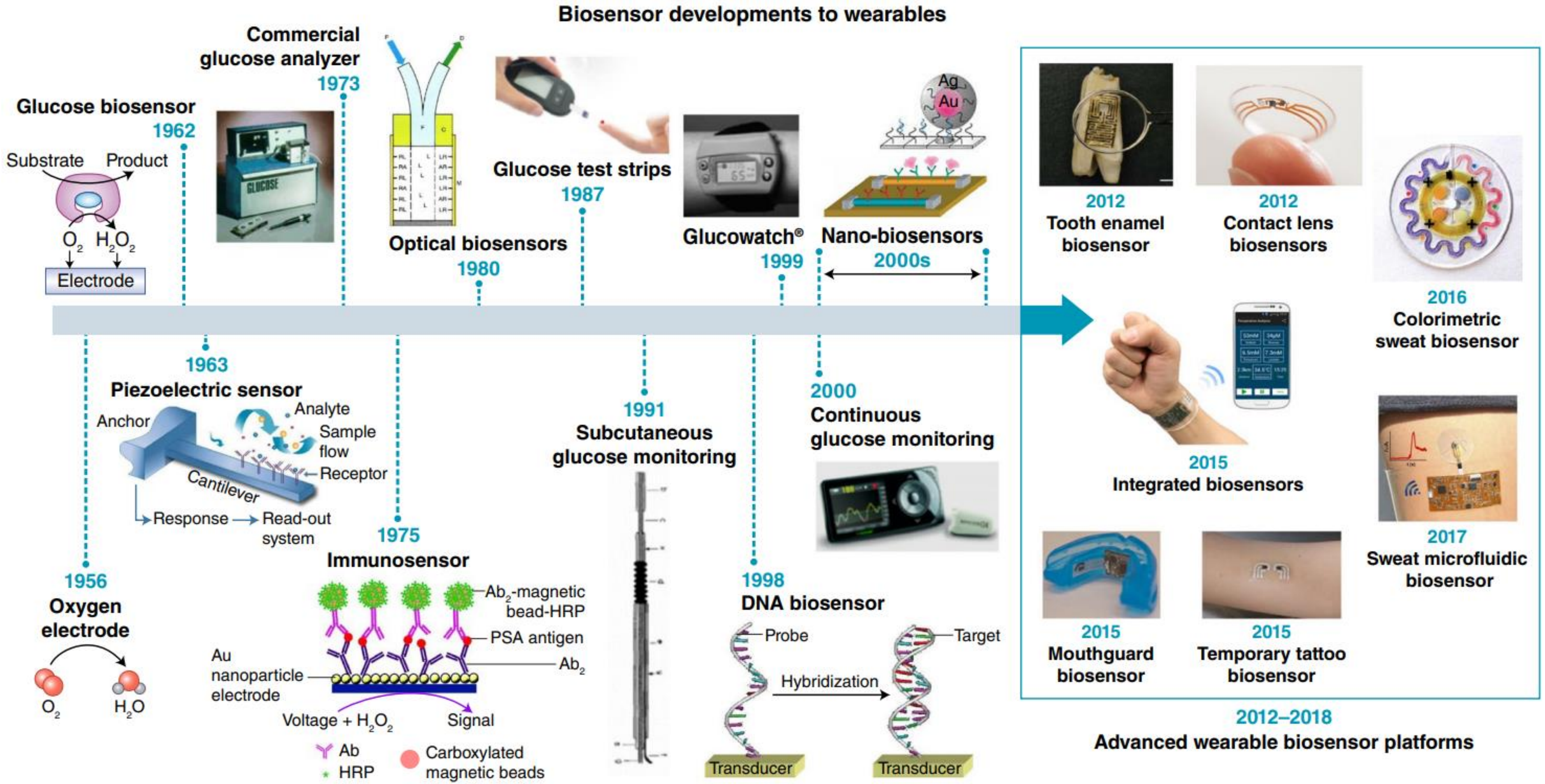
improve, simplify & accelerate

healthcare flow and clinical management

What is a biosensor?

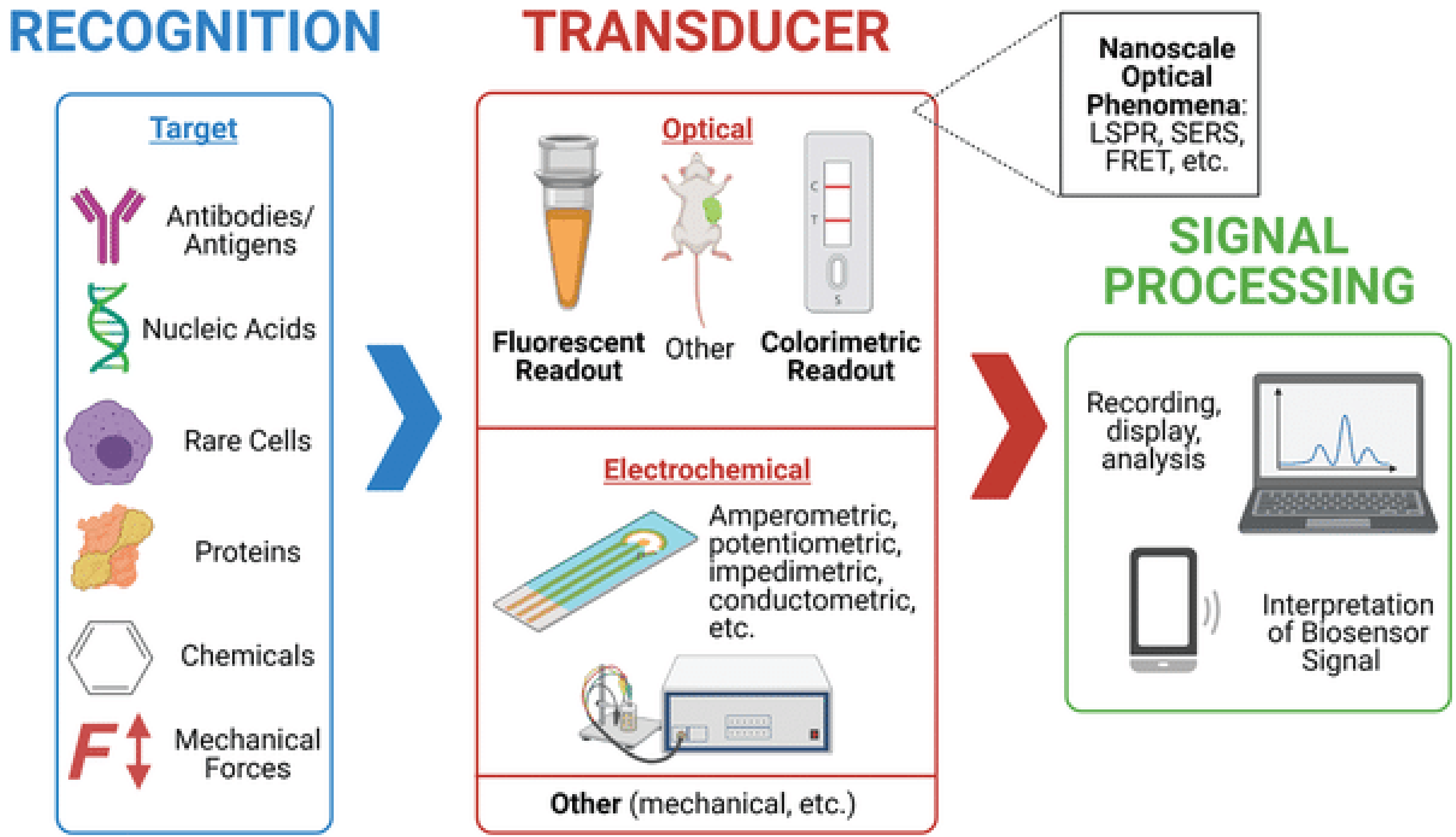


History of biosensor

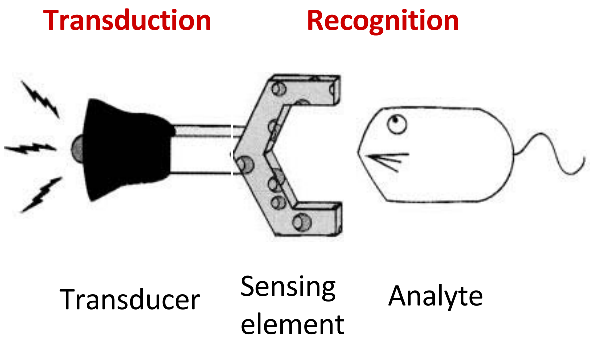


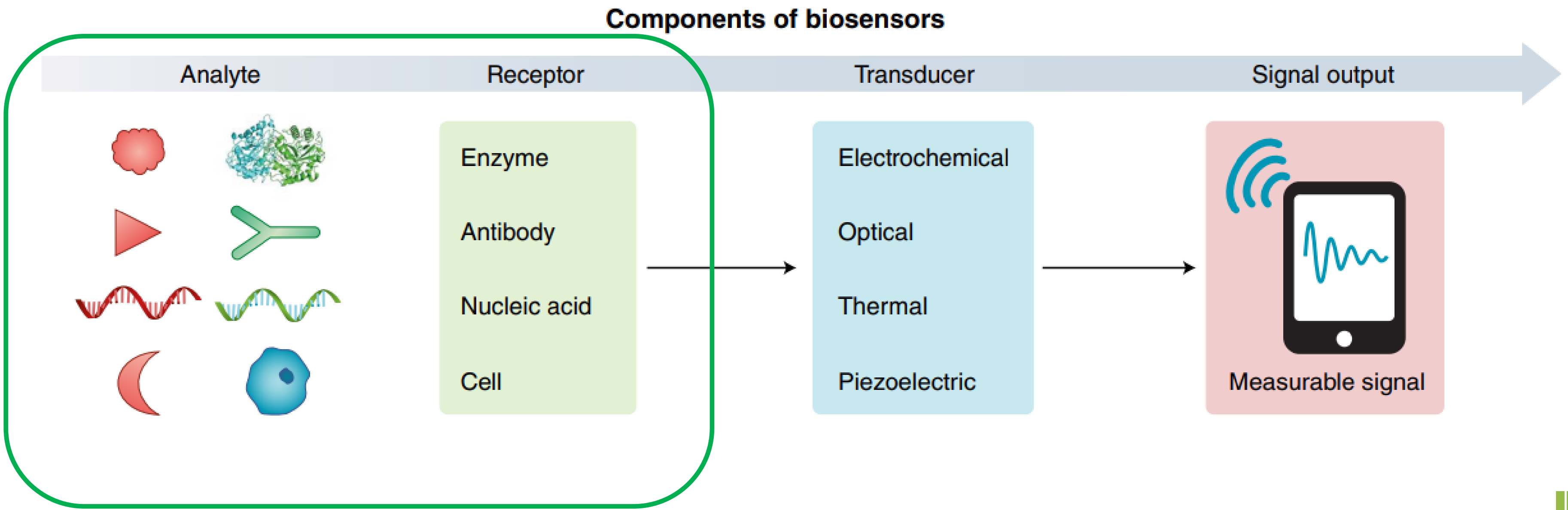

Biosensors Market
Global Forecast to 2026
Biosensors Market
is expected to reach
USD 36.7 billion by 2026
Growing at a
CAGR of 7.5% (2021-2026)

What is a Biosensor?

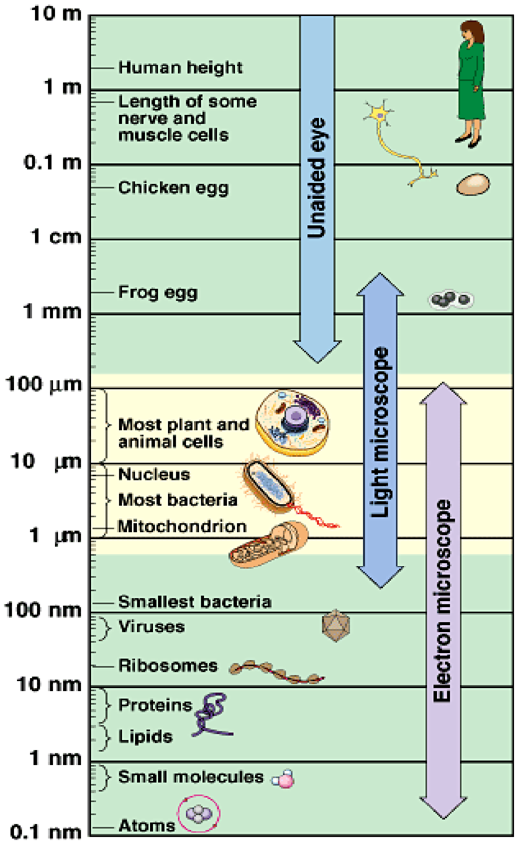


Structure of Biosensor



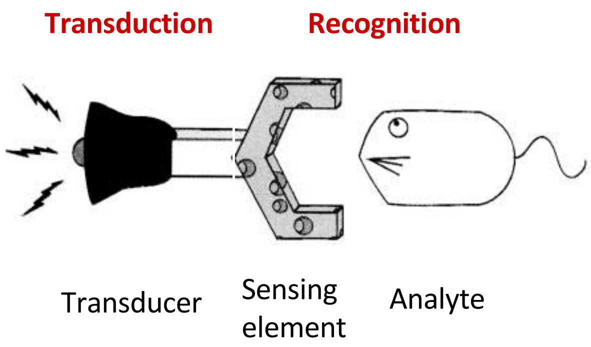


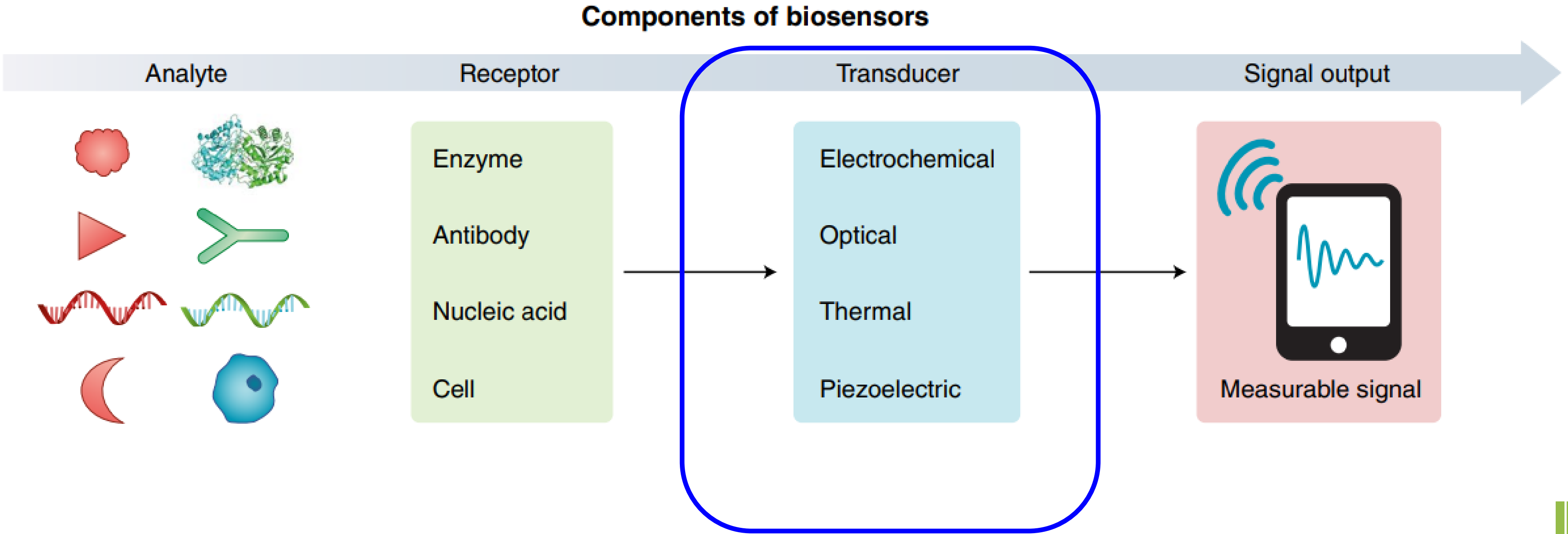
Relative sizes of cells and their components



Structure of Biosensor

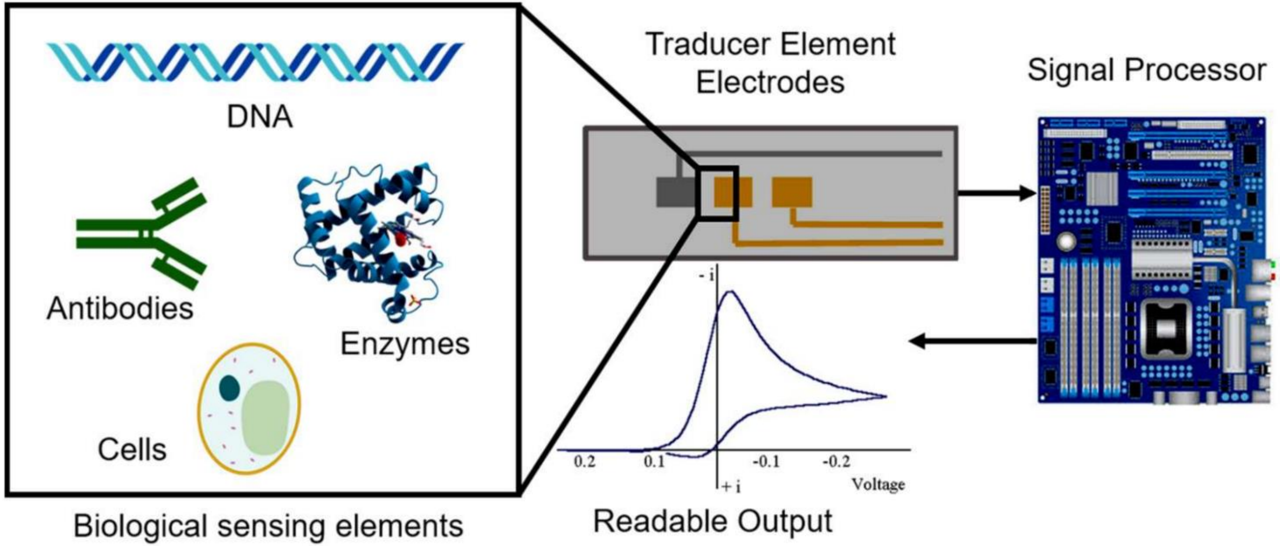
- **Biorecognition** (ligand): facilitate **specific** binding to or biochemical reaction with a **target**
- **Transduction**: converts a biological binding event to a measurable transduction signal





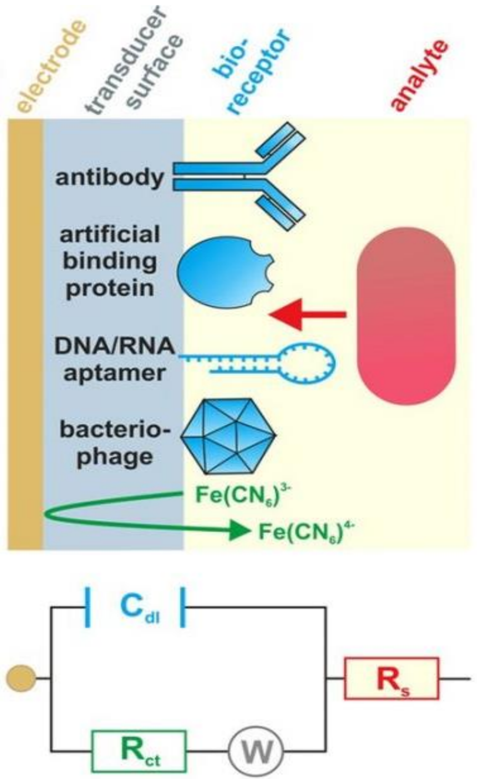
Electrochemical biosensor

Electrochemical biosensor is based on the reaction that consumes or generates electrons. The substrate of this biosensor generally includes three electrodes such as a counter, reference, and working type.



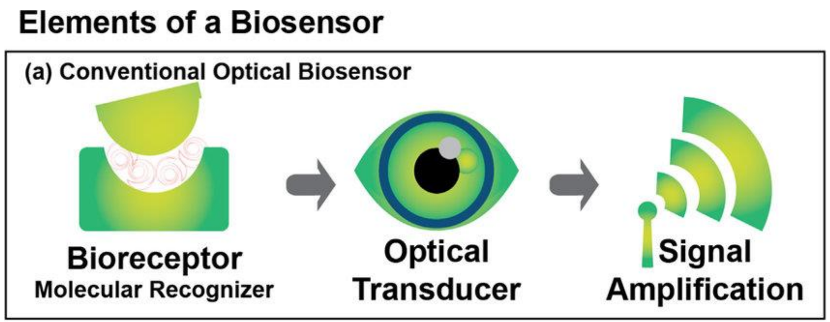
Electrochemical biosensor

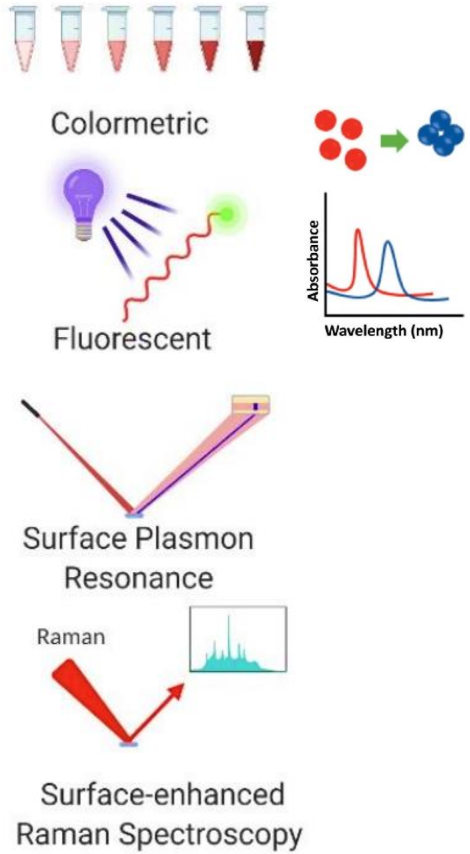
- **<u>Potentiometric</u>**
  - Measurement of the open-circuit potential between two electrodes immersed in solution
  - Usually gives a log[concentration] – voltage relationship
    - Useful for wide dynamic range sensing
- **<u>Voltammetric</u>**
  - Measurement of the voltage-current characteristics between two or three electrodes
  - <u>Amperometric</u> sensors are a sub-class where the voltage of the sensor is kept ~constant and the current is read out
  - Usually gives a linear current-voltage relationship
    - Useful for high sensitivity across a small linear range
- **<u>Conductometric</u>**
  - Measurement of the impedance of a sensor at one or multiple frequencies



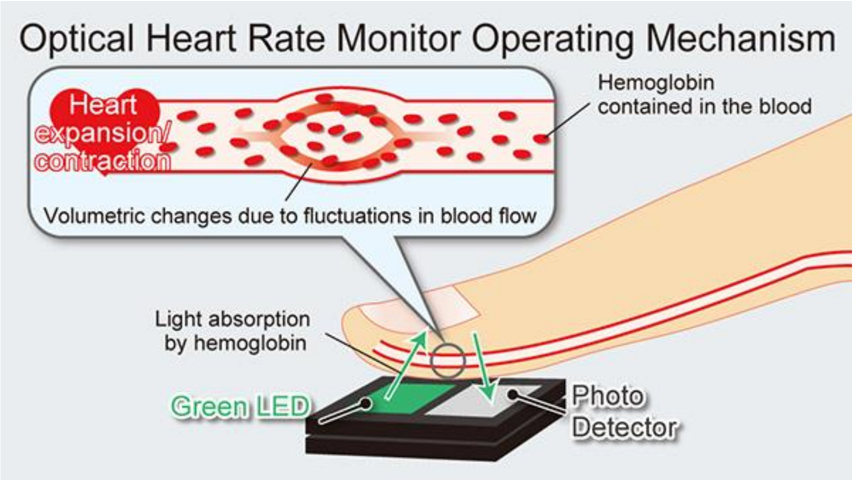
Optical biosensor

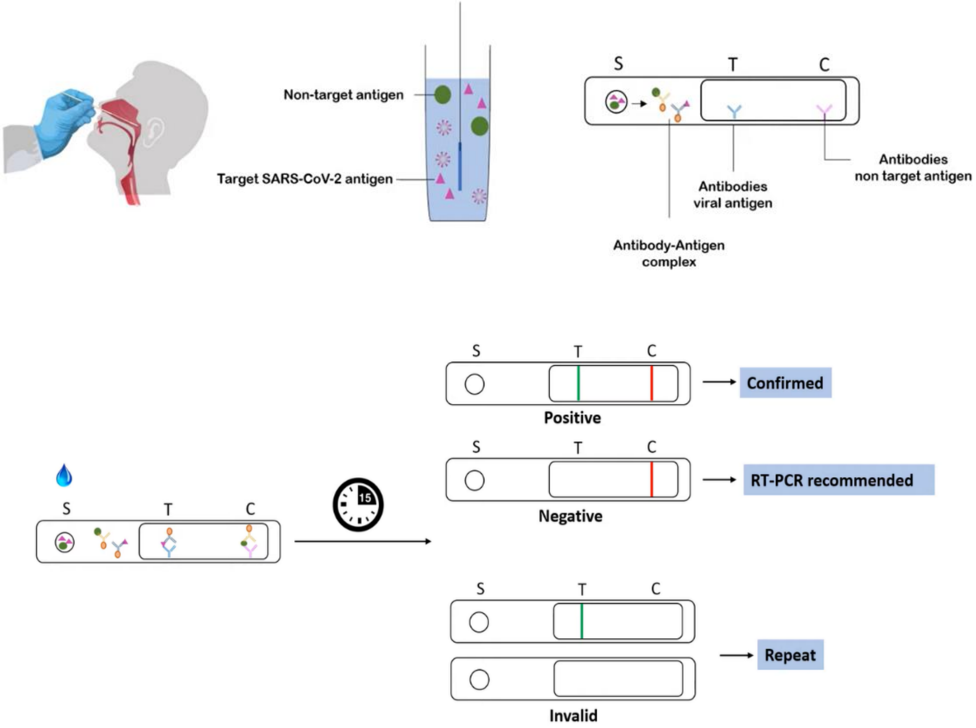
- Most common type of biosensor- remote, noninvasive, wireless
- Light property changes after reactions, such as color, intensity, wavelengths, absorption, reflections.
- Compact analytical device containing a biorecognition sensing element integrated with an optical transducer system





Optical biosensor

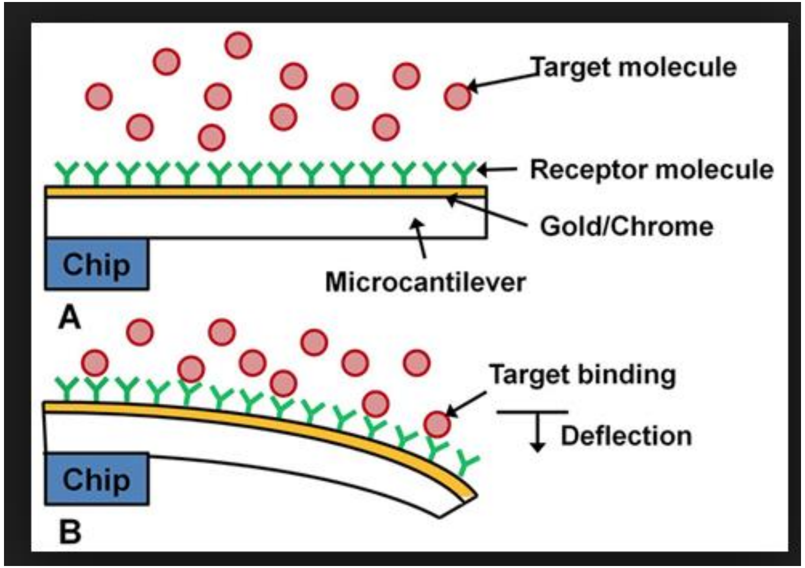




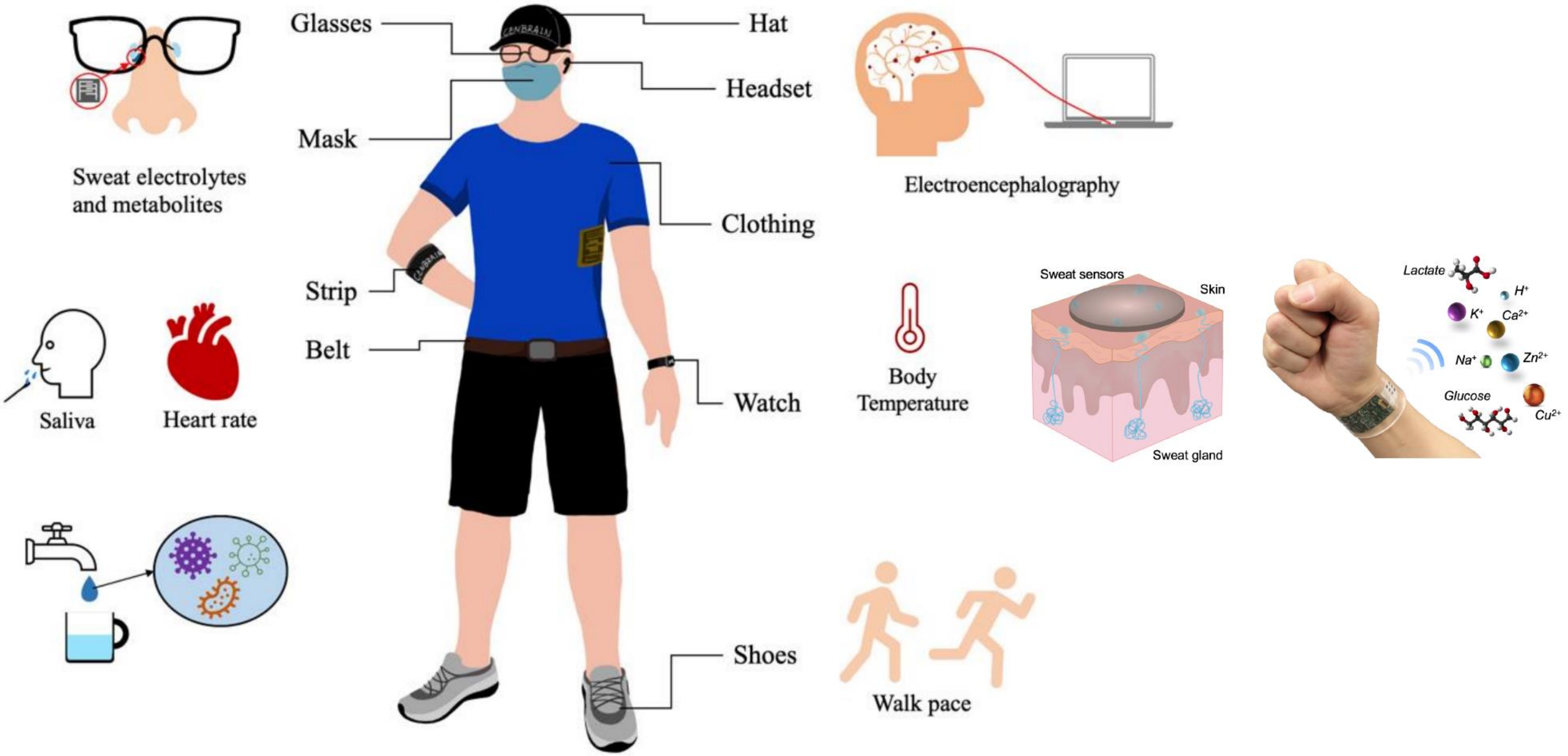
Mechanical biosensor

- Mechanical biosensors utilize mechanical properties to detect and analyze viruses, offering advantages like high sensitivity and reagent-free operation.

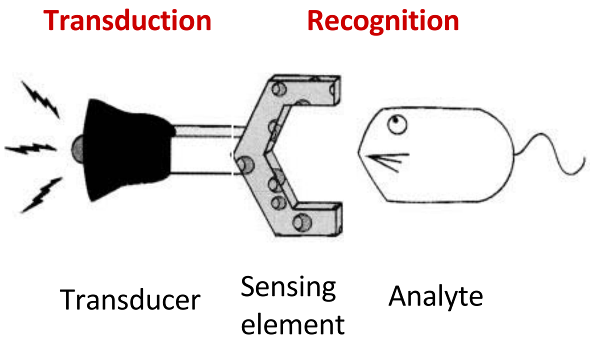
- Schematic representation of the mechanical biosensors based on micro-cantilever and its working principles, (a) static mode and (b) dynamic mode

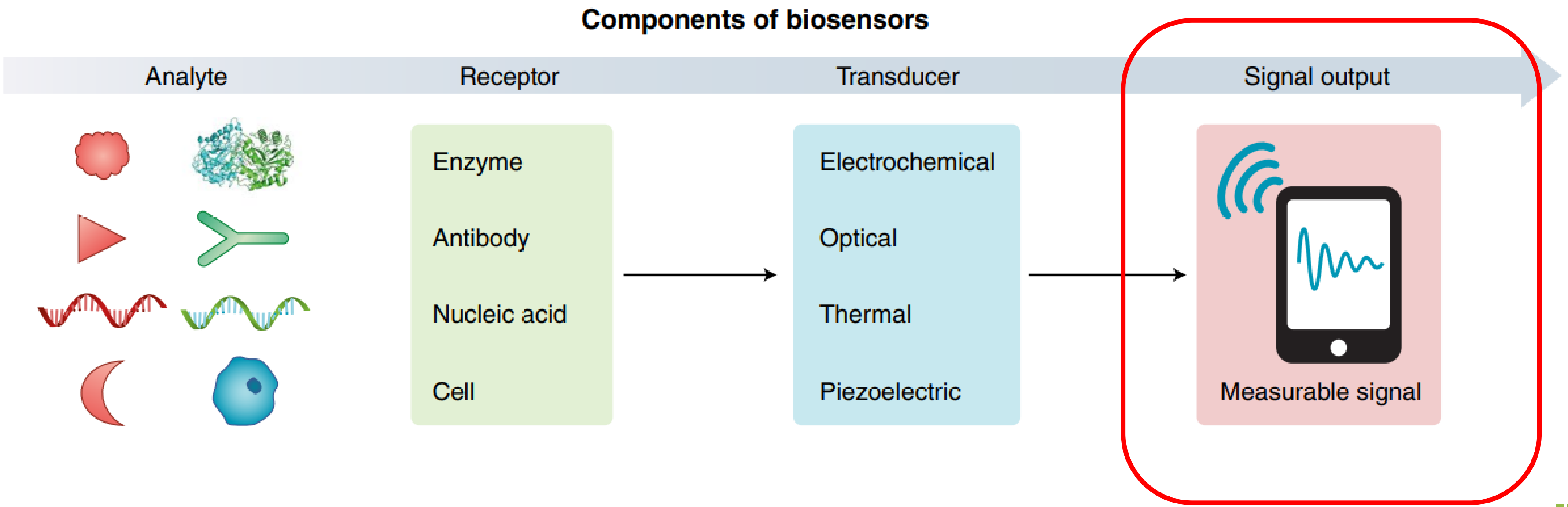


Wearable Biosensor

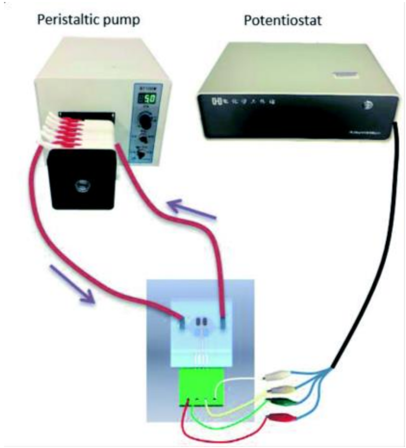


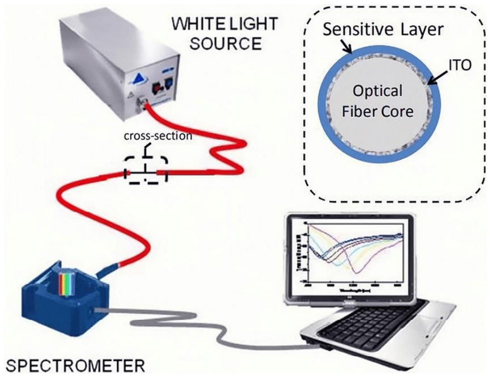
Structure of Biosensor

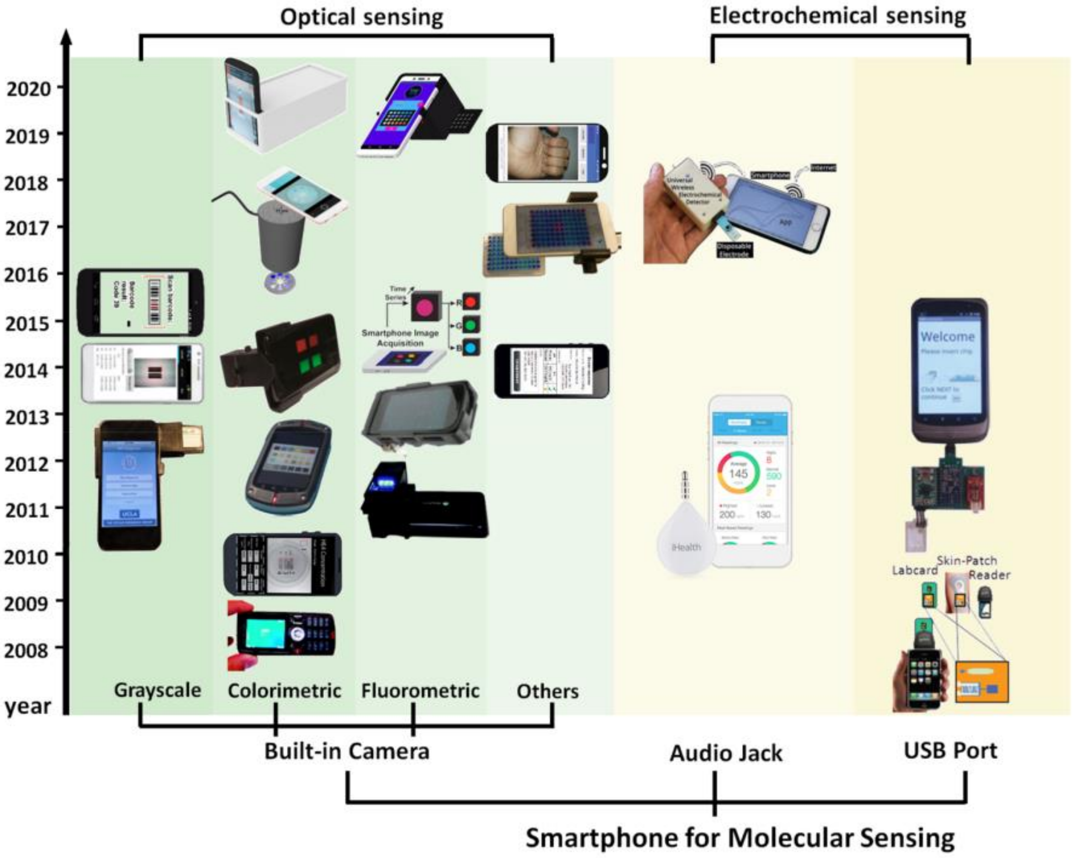




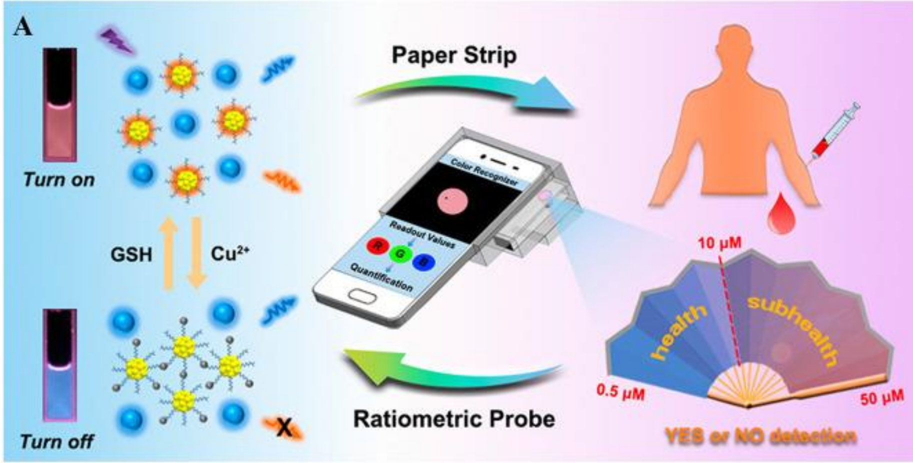
Signal Readout

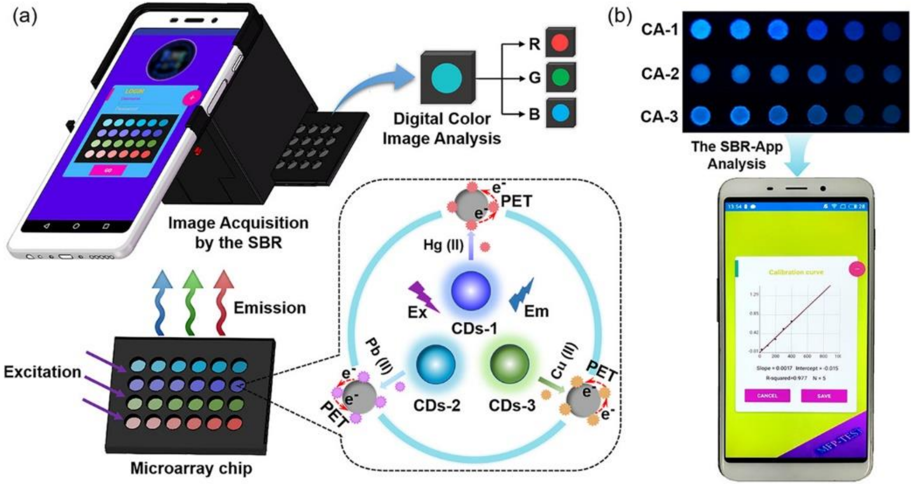




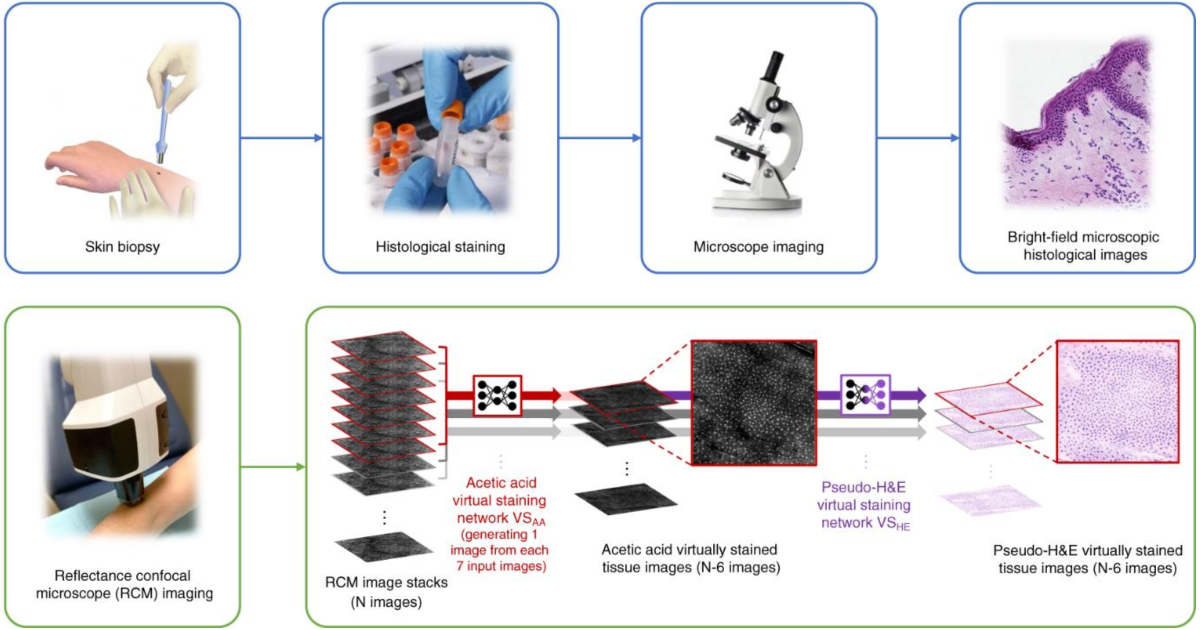


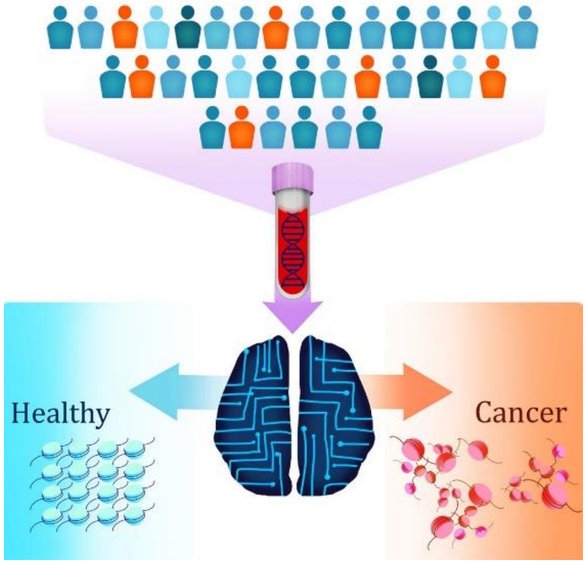
Signal Readout & Analysis

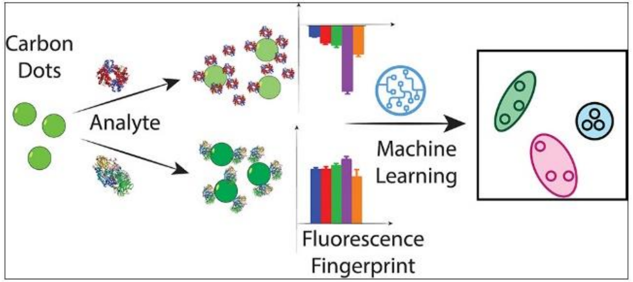




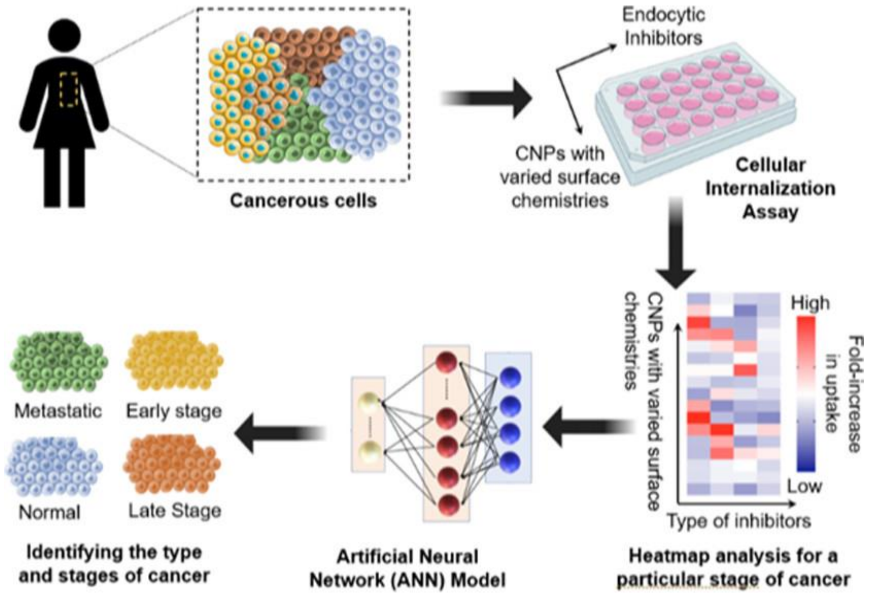
Machine Learning Analysis

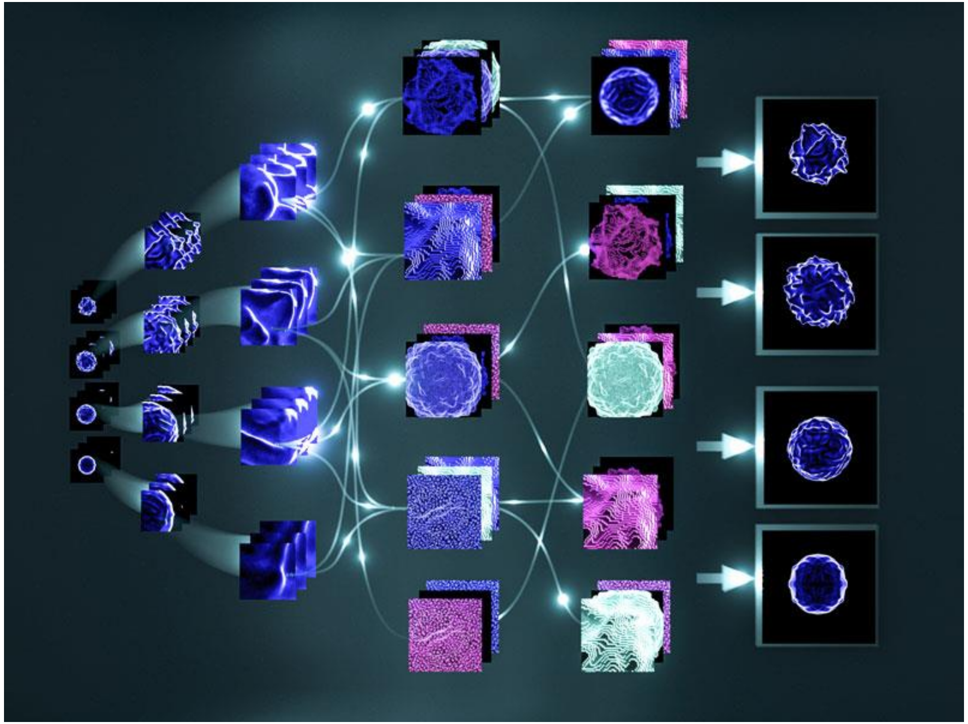






Machine Learning Analysis

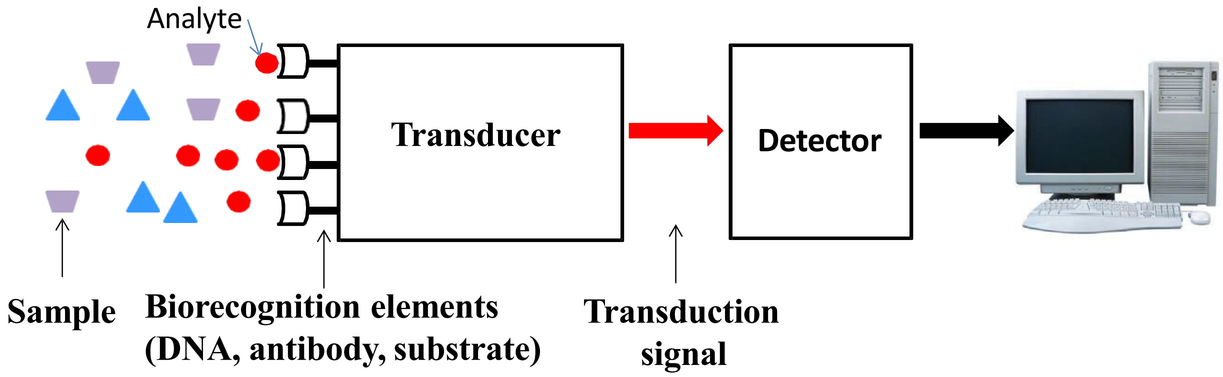




3

Applications of Optical Biosensors

Key Parameters of Biosensors



A biosensor answers two fundamental questions:

1. What is the analyte being measured (**specificity**)
2. The quantity (or concentration) of the analyte (**sensitivity**)

Detection limit/
Limit of detection (LOD)

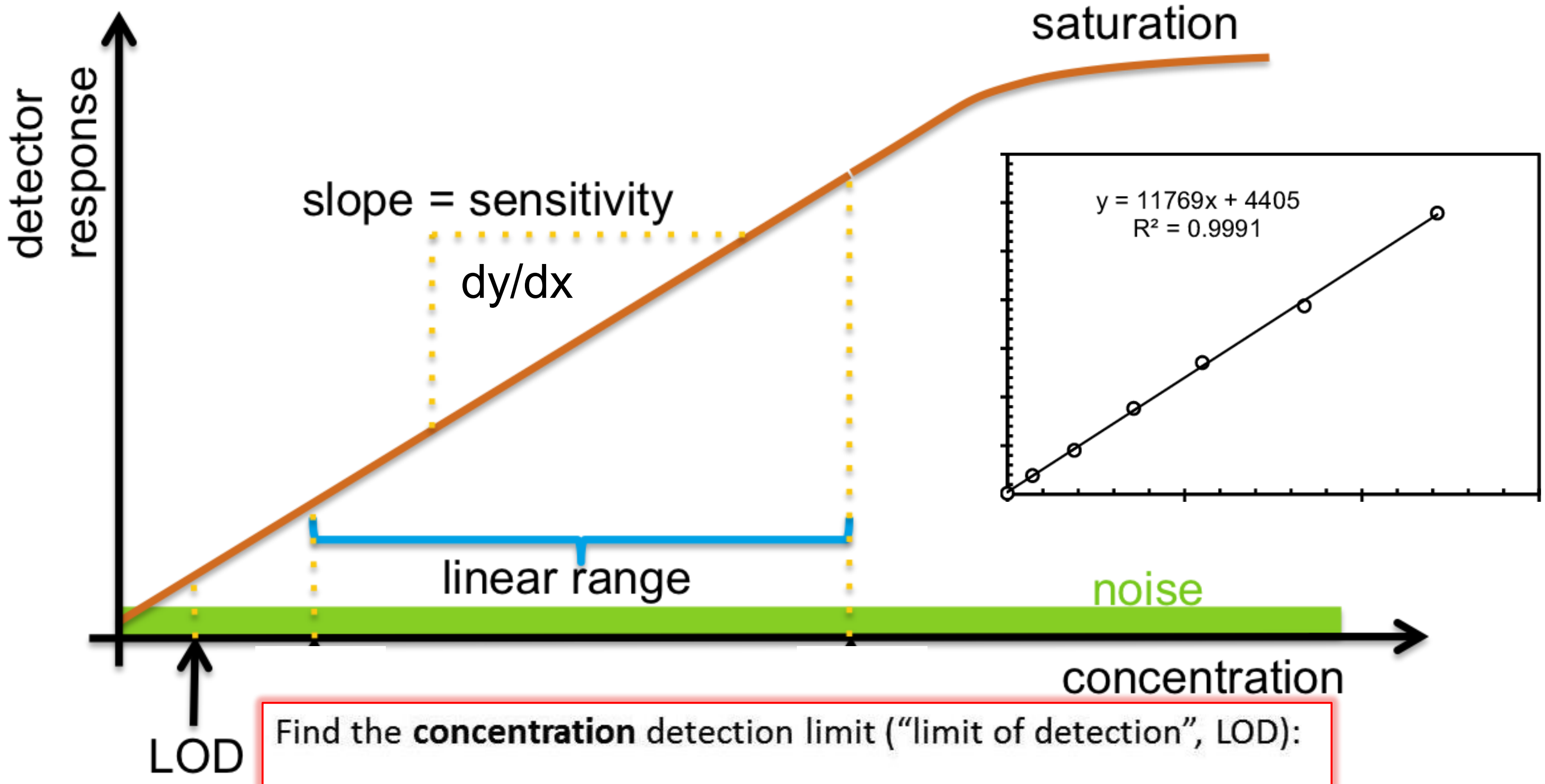
Key Parameters of Biosensors

1. LINEARITY (high)	Linearity of the sensor should be high for the detection of high analyte/substrate concentration
2. SENSITIVITY (high)	Value of the sensor response per analyte/substrate concentration
3. SELECTIVITY (high)	Chemicals interference have to be minimized for obtaining the correct result
4. RESPONSE TIME (short)	Time necessary for having 95% of the response
5. REPRODUCIBILITY *(high)*	The ability of the biosensor to generate identical responses for a duplicated experimental set-up

Sensitivity VS. Limit of Detection

- **NOT THE SAME THING!!!!!**
- Sensitivity: Ability to discriminate between small differences in analyte concentration at a particular concentration.
  - calibration sensitivity—the slope of the calibration curve at the concentration of interest
- Limit of detection: Minimum concentration that can be detected at a known confidence limit

Sensitivity VS. Limit of Detection



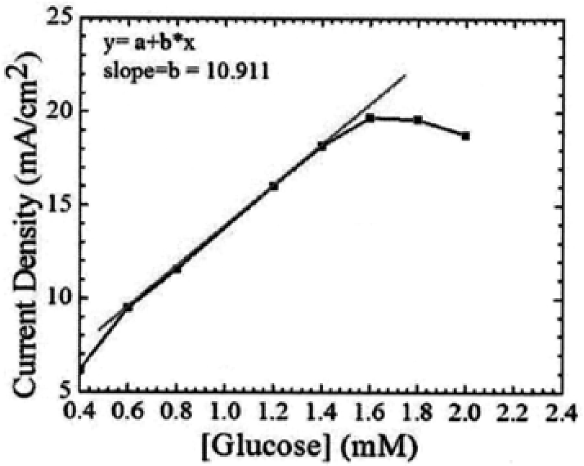
Find the **concentration** detection limit (“limit of detection”, LOD):

$$LOD = \frac{3s}{m}$$

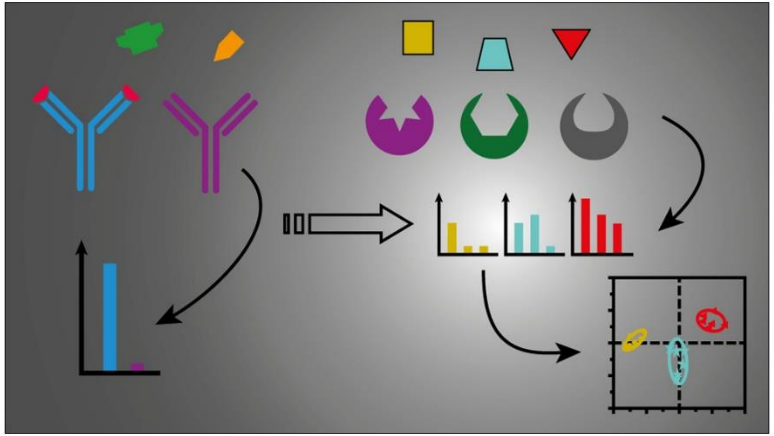
Example 1:

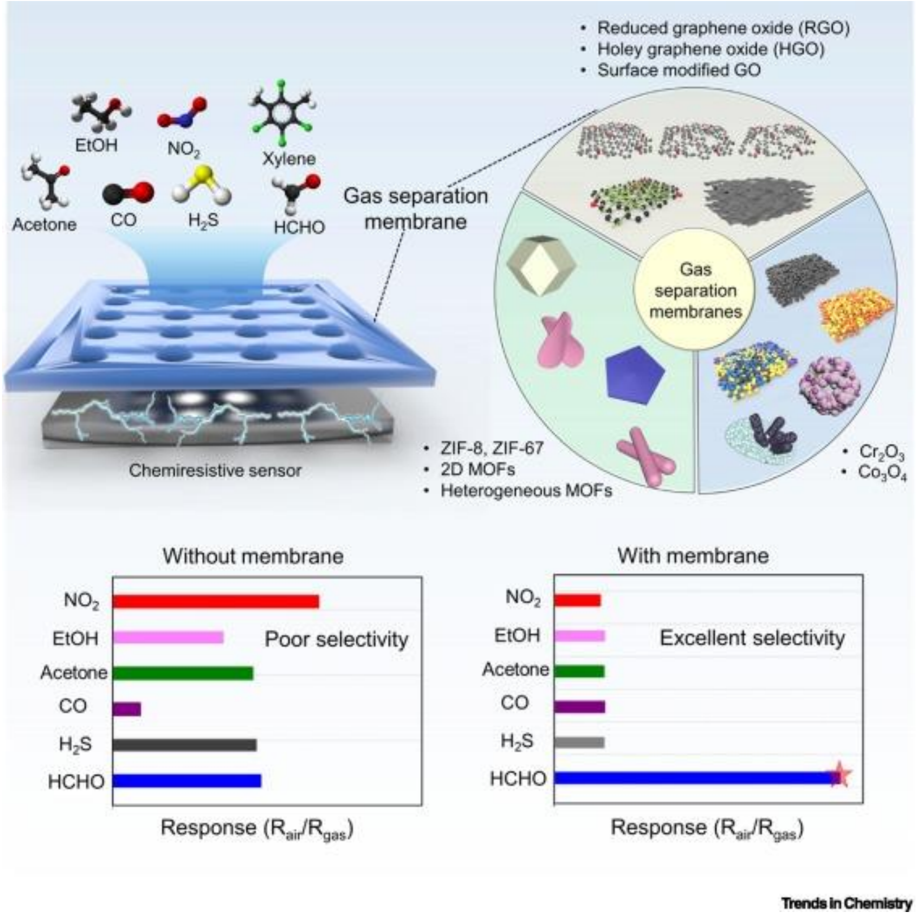
Below shows the performance of an glucose biosensor, the current measured under different glucose concentrations. What is the limit of detection? (Standard deviation is ~2 mA).

0.55 mM cm^{-2}
5.5 mM cm^{-2}
1.1 mM cm^{-2}
10.91 mM cm^{-2}
5.45 mM cm^{-2}



Selectivity

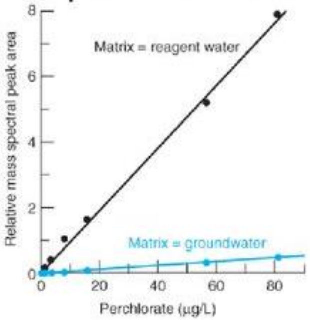




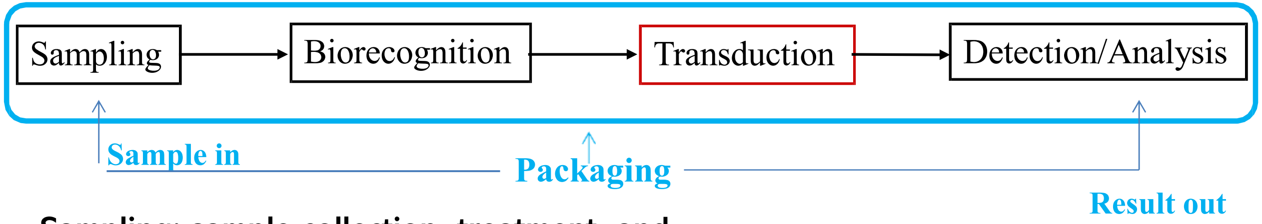
Sensitivity VS. Selectivity

- **Selectivity (specificity):**
  - *distinguish analyte from other species in the sample (avoiding* interference).
- **Sensitivity:**
  - Capability of responding reliably and measurably to changes in analyte concentration
  - The *detection limit of an analytical method must be lower than* the concentrations to be measured.
  - Slope of the calibrations curve
  - Example: method below is more sensitive for perchlorate in reagent water than in groundwater.

$$slope = \frac{\Delta\ signal}{\Delta\ analyte\ concentration}$$



Key Elements



Sampling: sample collection, treatment, and delivery

- How to rapidly collect samples?
- How to concentrate samples and remove unwanted samples?
- How to efficiently deliver samples with minimal loss and high speed?
- (Micro) fluidics - Concentration increase/decrease, Filtration/selection

Biorecognition: surface immobilization, surface treatment to minimize …

- How to efficiently immobilize probes to maximize the capture?
- How to minimize the non-specific binding?

Transduction:

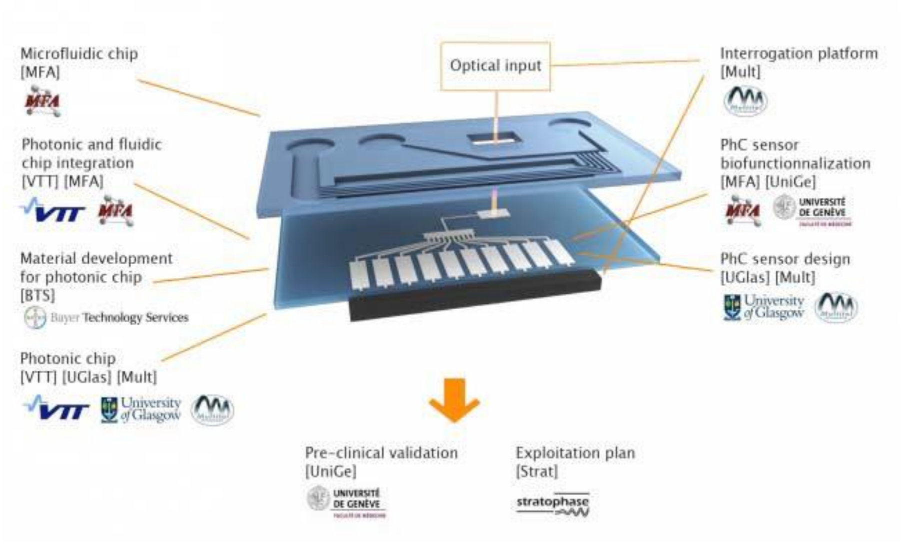
- How to improve the sensitivity or detection limit?
- How to improve the detection speed and multiplexing capability?

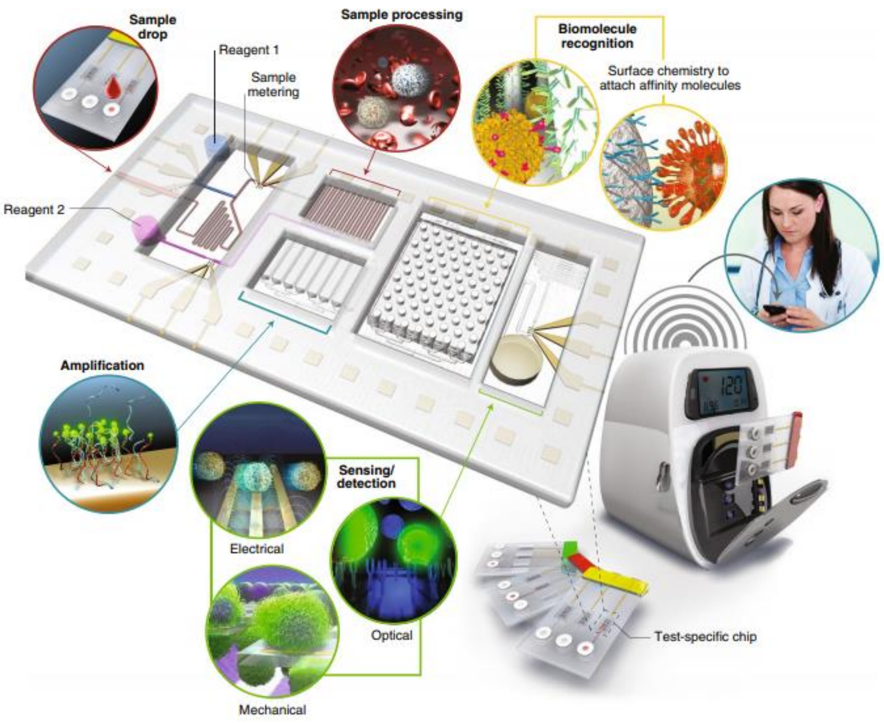
Detection/analysis:

- How to develop a good algorithm to extract the useful biological information

Packaging and Cost: extremely important in successful commercialization

Integrated Biosensor

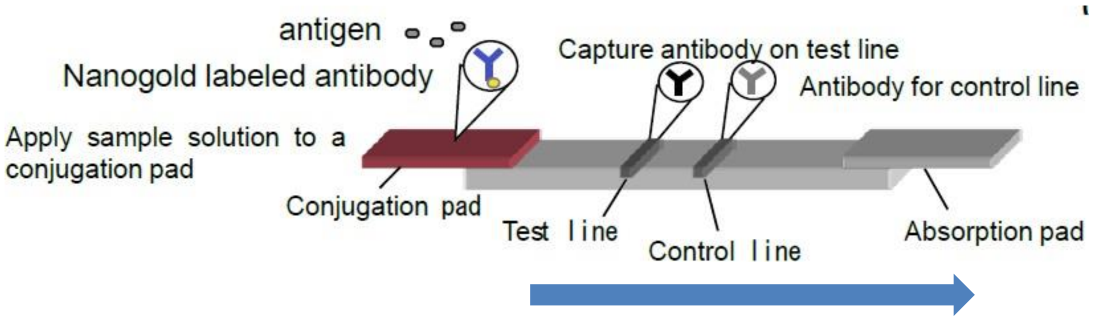




Example of Optical Biosensor in Daily Life

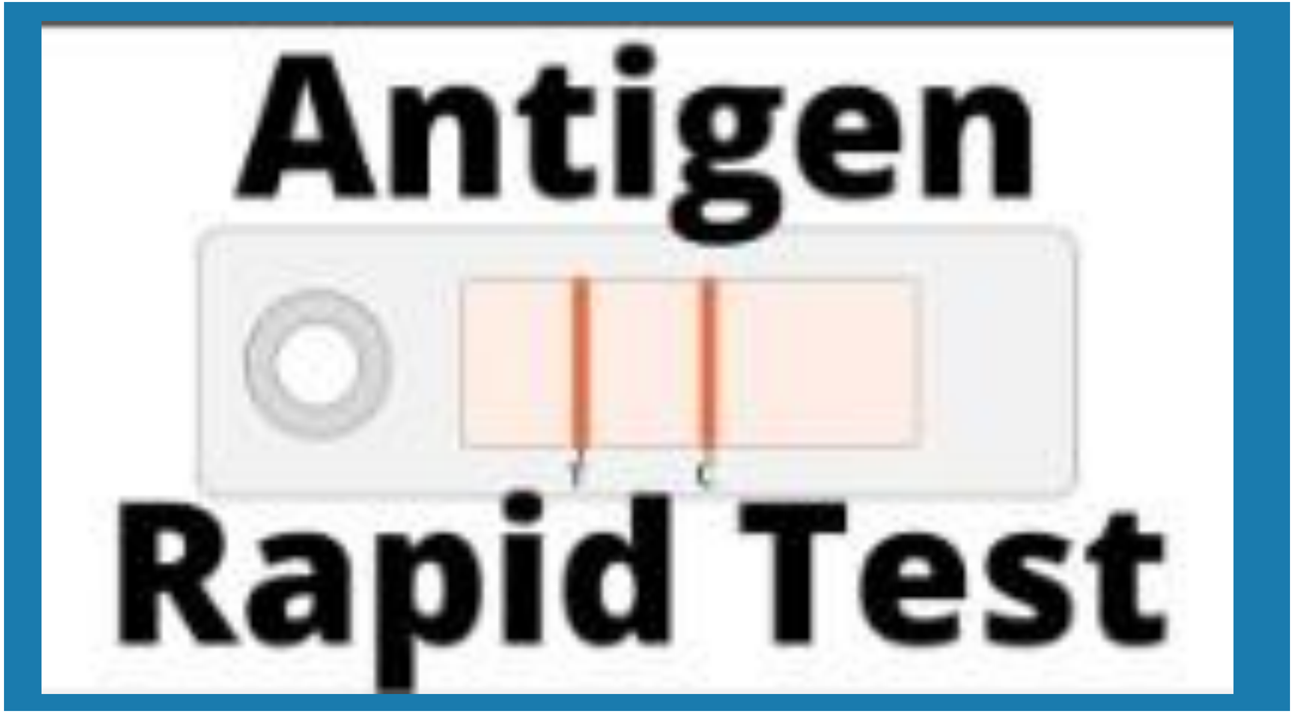
<u>Pregnancy test</u>

Detects the hCG hormone in urine.



Flow direction

Applications of Optical Biosensors



Applications of Optical Biosensors

- **DNA chip or biochip**
- Consists of a small glass plate encased in plastic
- Collection of microscopic DNA spots attached to a solid surface
- Used to measure gene expression level
- Each spot contains multiple copies of a unique DNA sequence

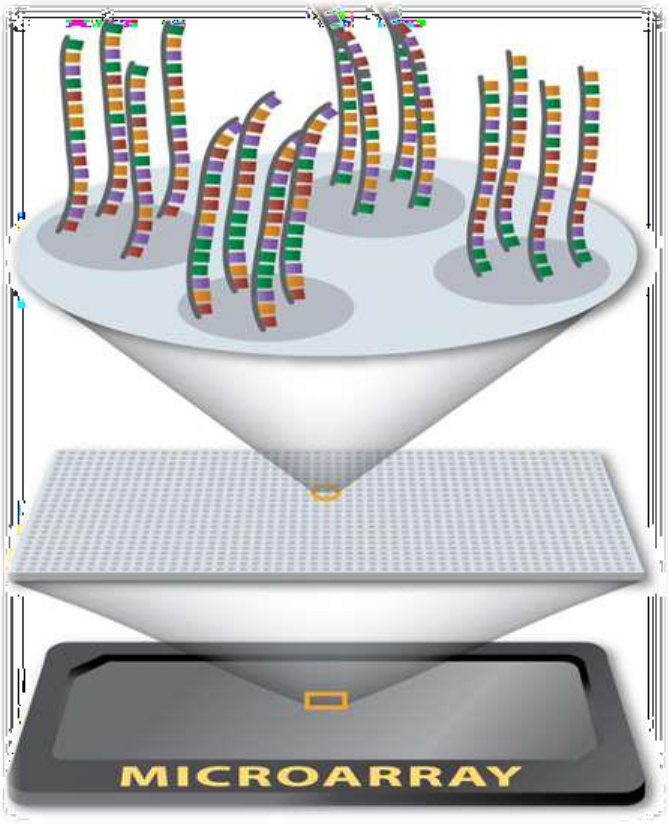
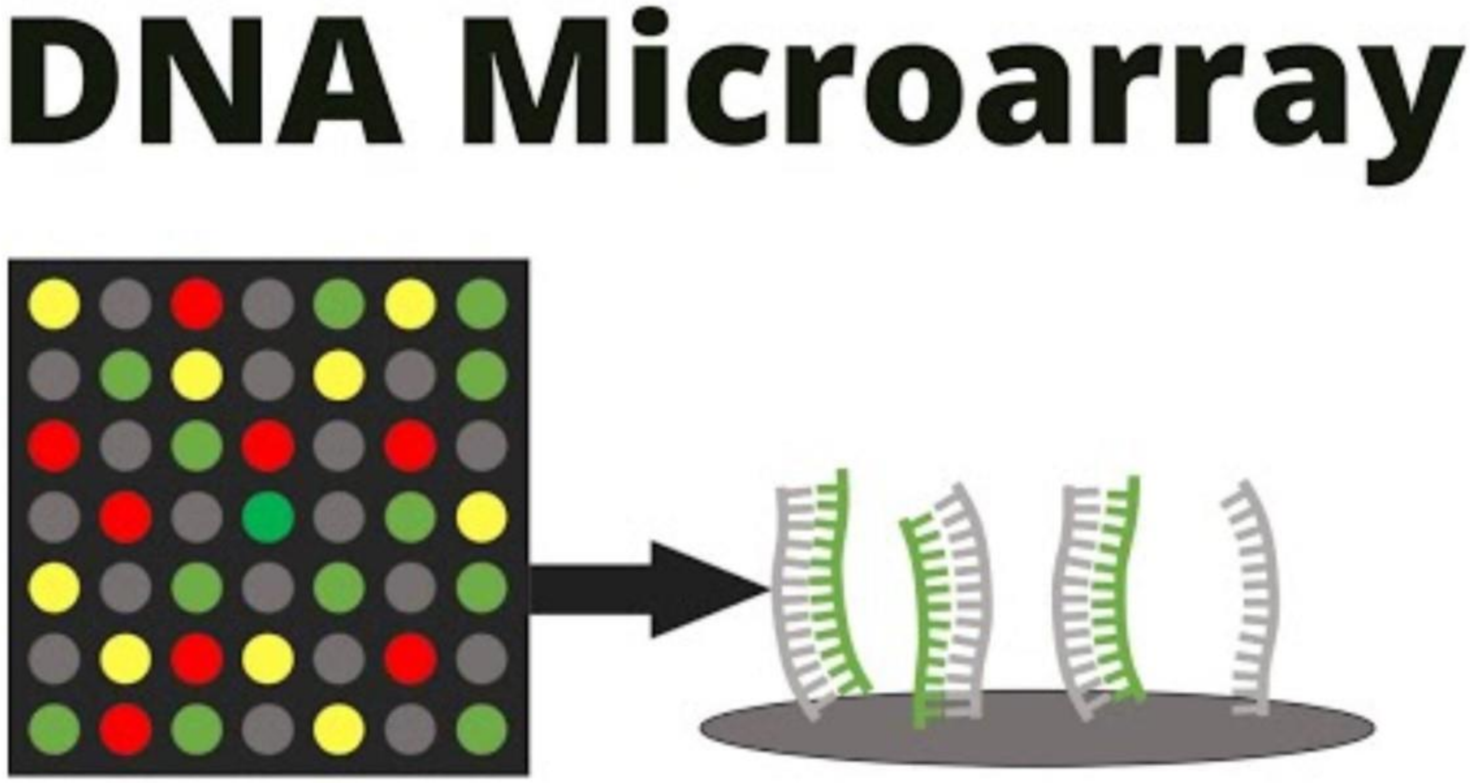


Image retrieved from www.learn.genetics.utah.edu

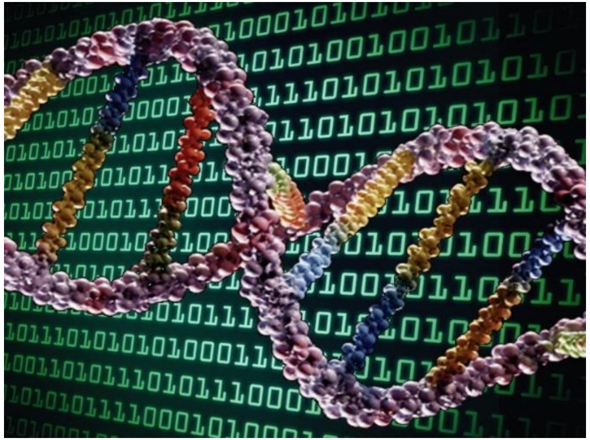
Applications of Optical Biosensors

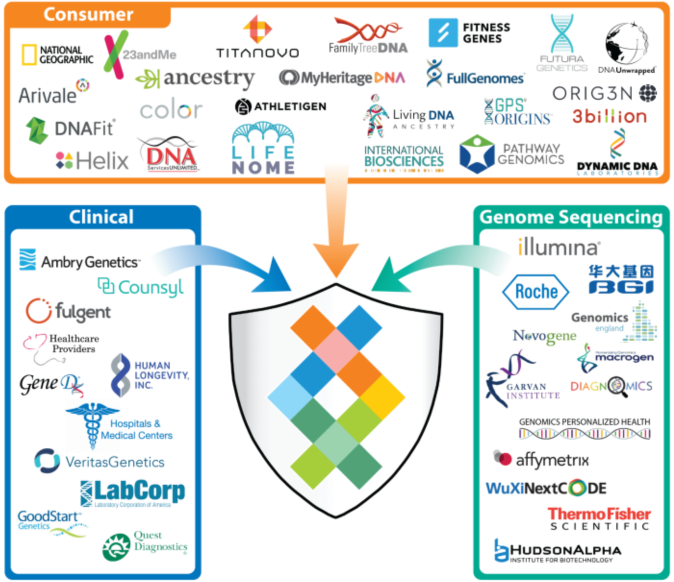


DNA Biochips

- Gene Expression Profiling
- Disease Diagnosis
- Drug Discovery
- Toxicological Research

- Provides data for thousands of genes
- One experiment instead of many
- Huge step closer to discovering cures for diseases





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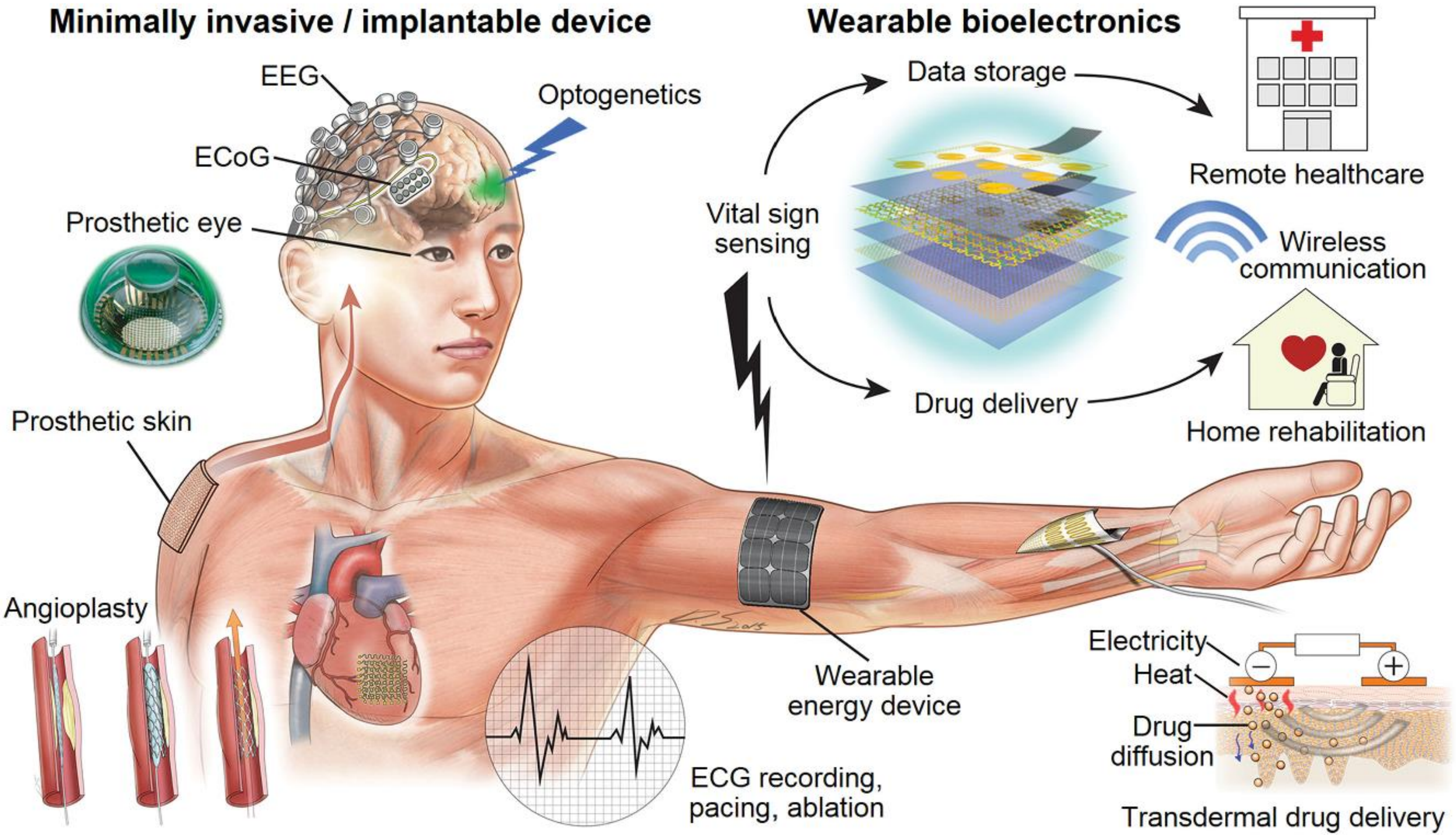
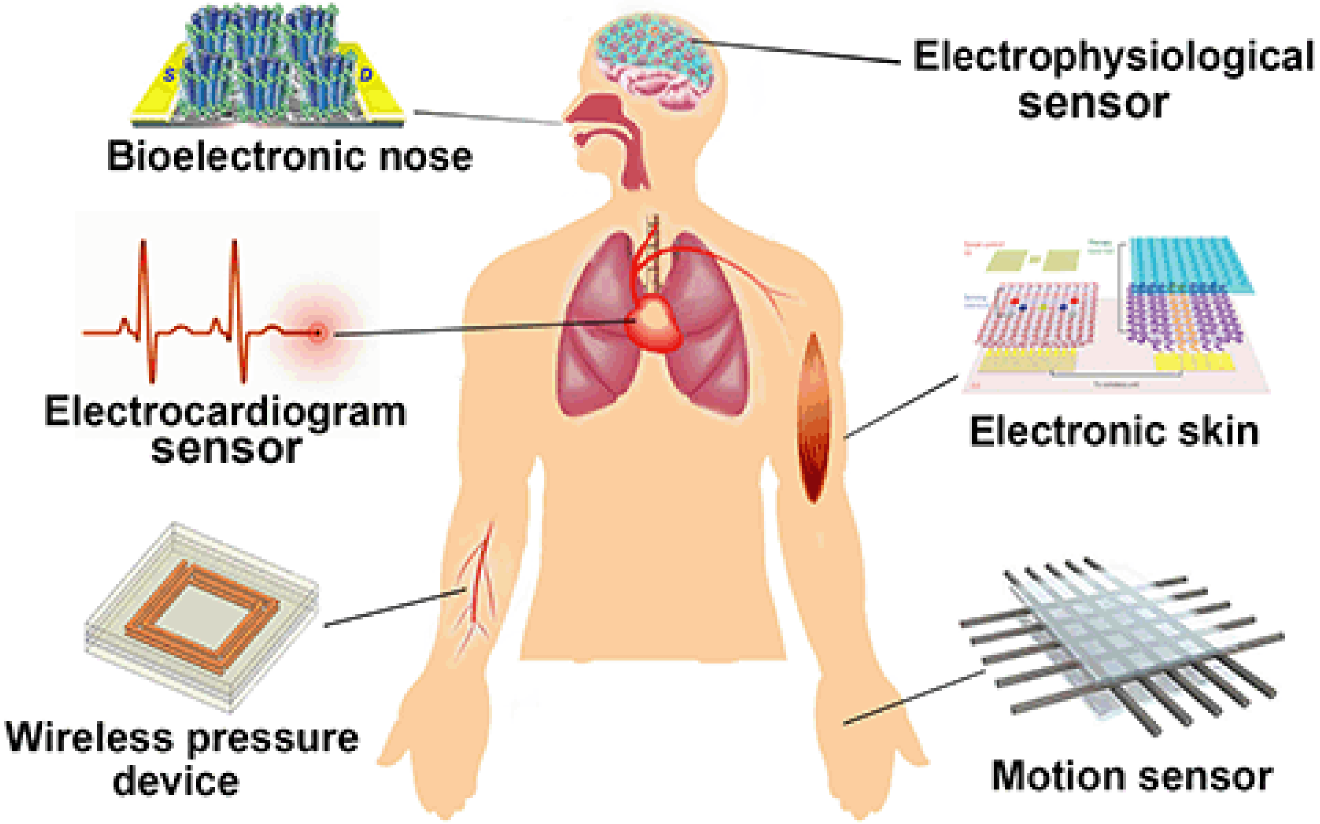
Applications of Electrical Biosensors

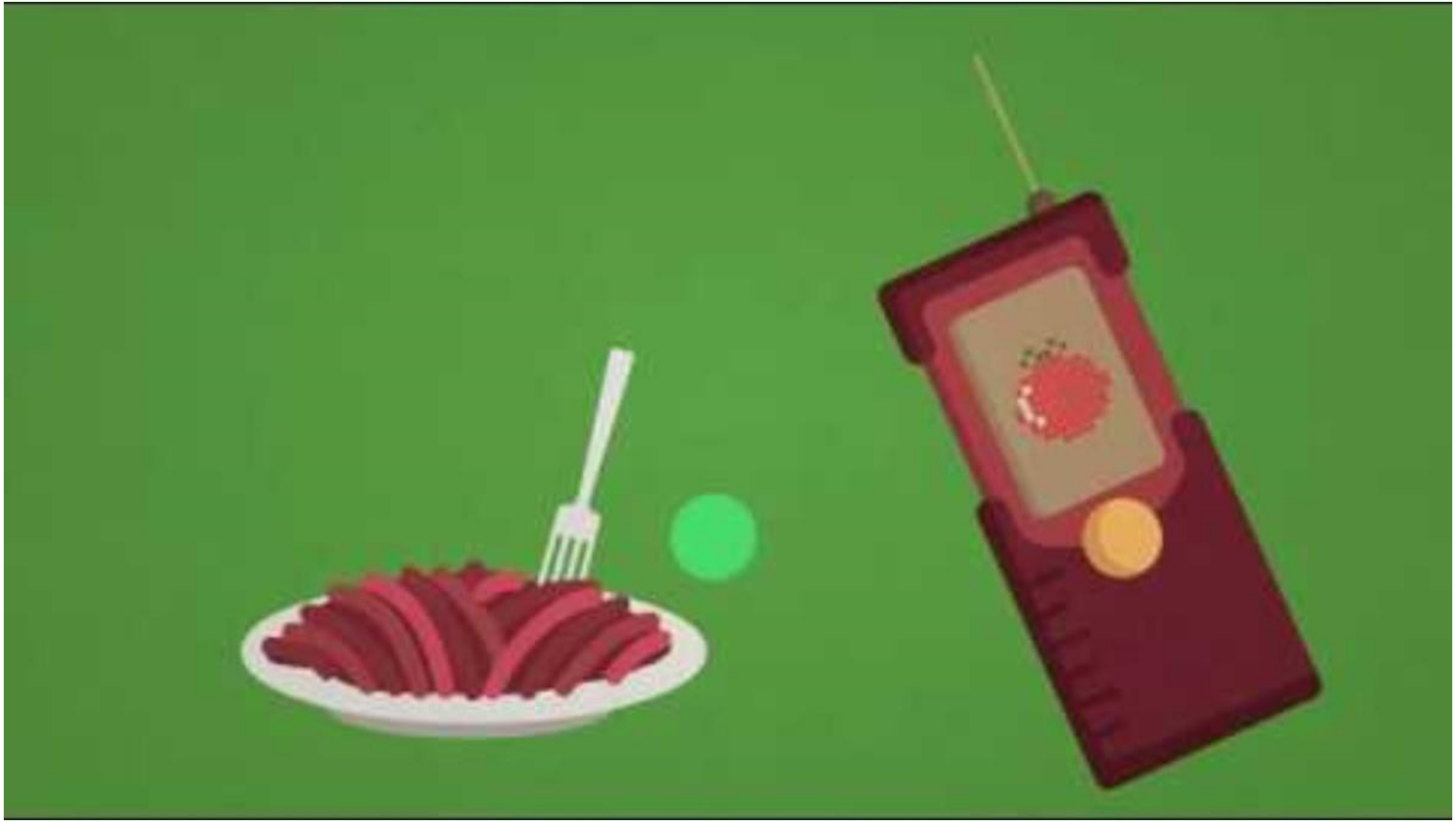
Electrical signals in our body



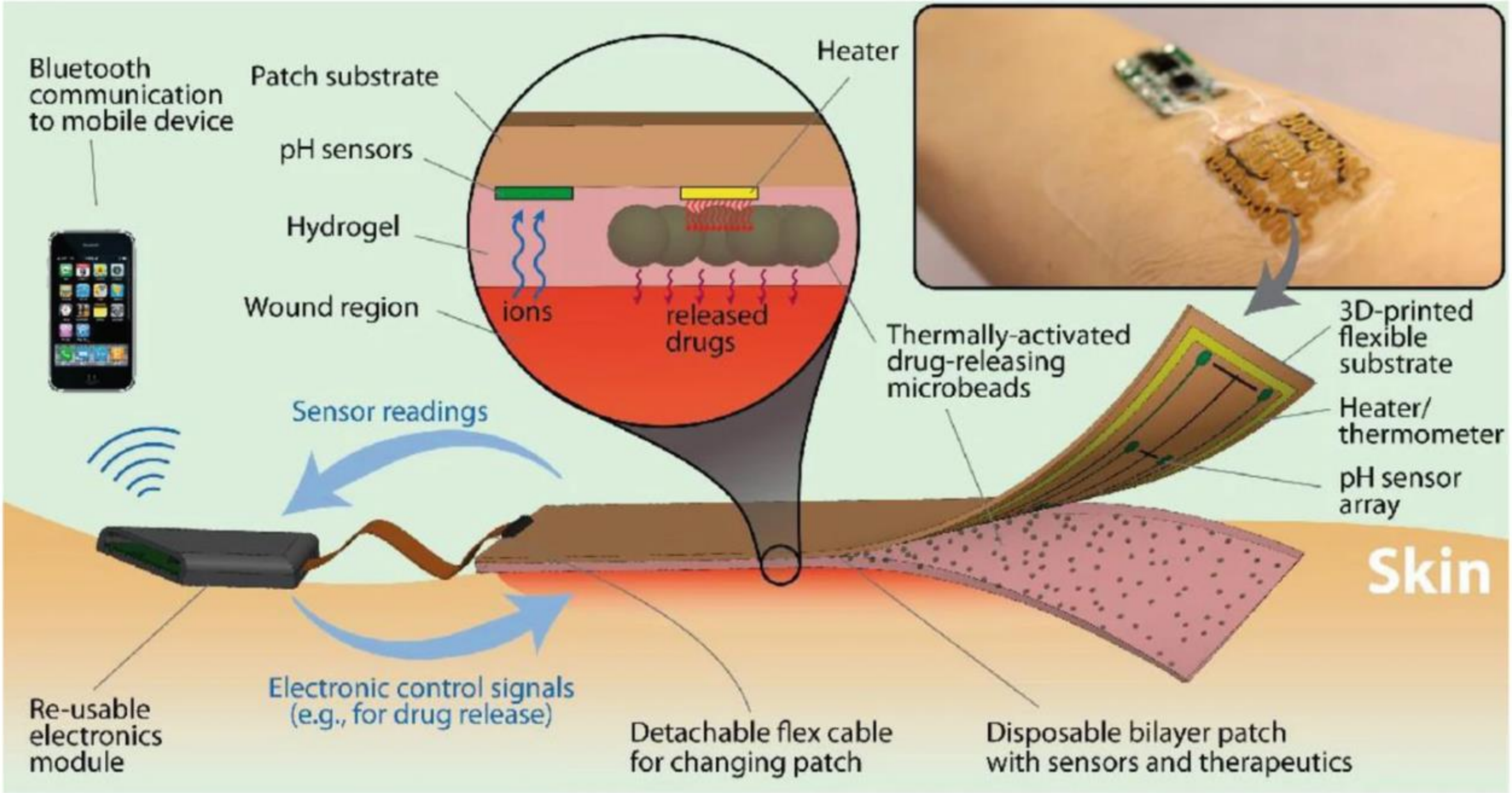
Applications of Electrical Biosensors



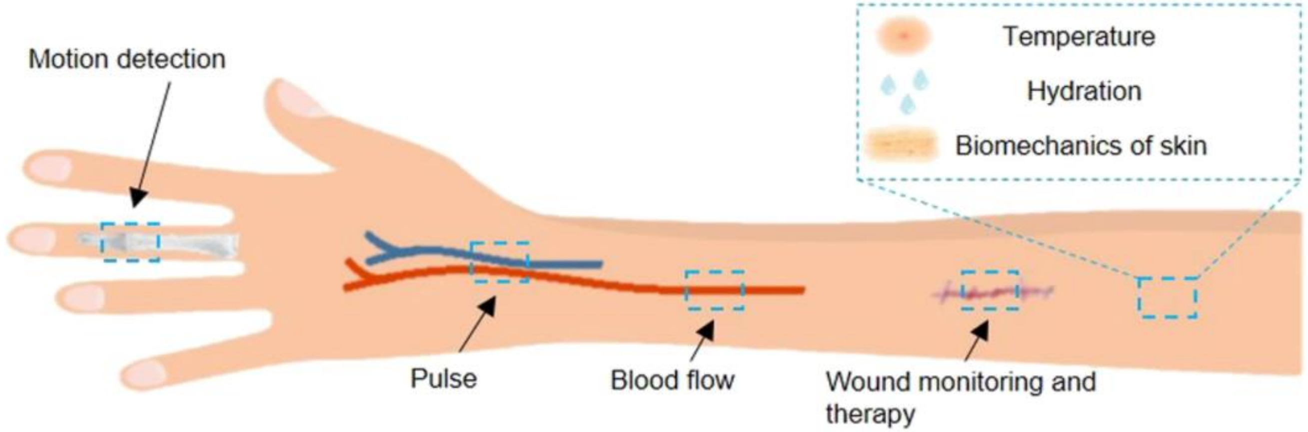
Electronic Nose?

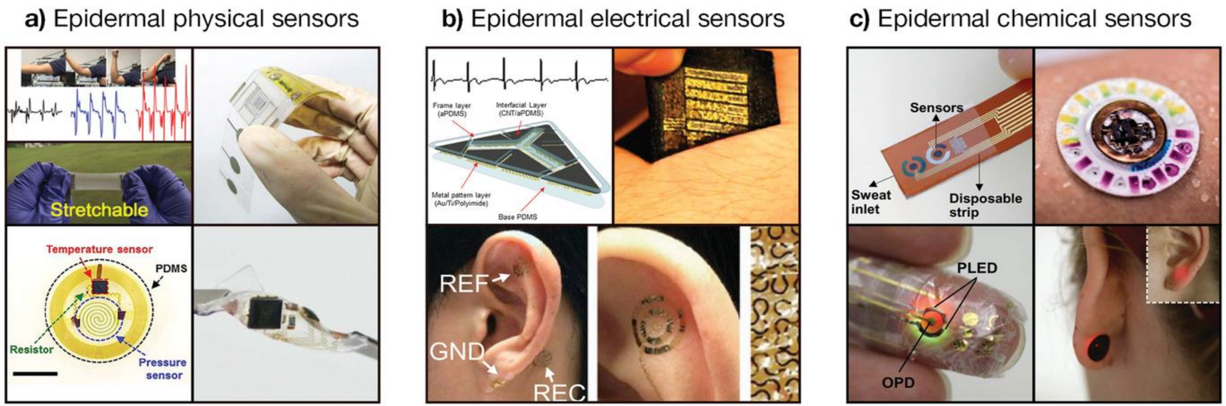


Advantages of Electrical Biosensors



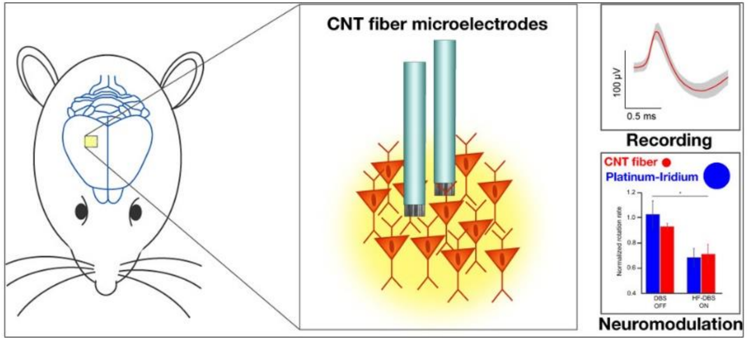
Sensing and Monitoring Bioelectrical signals

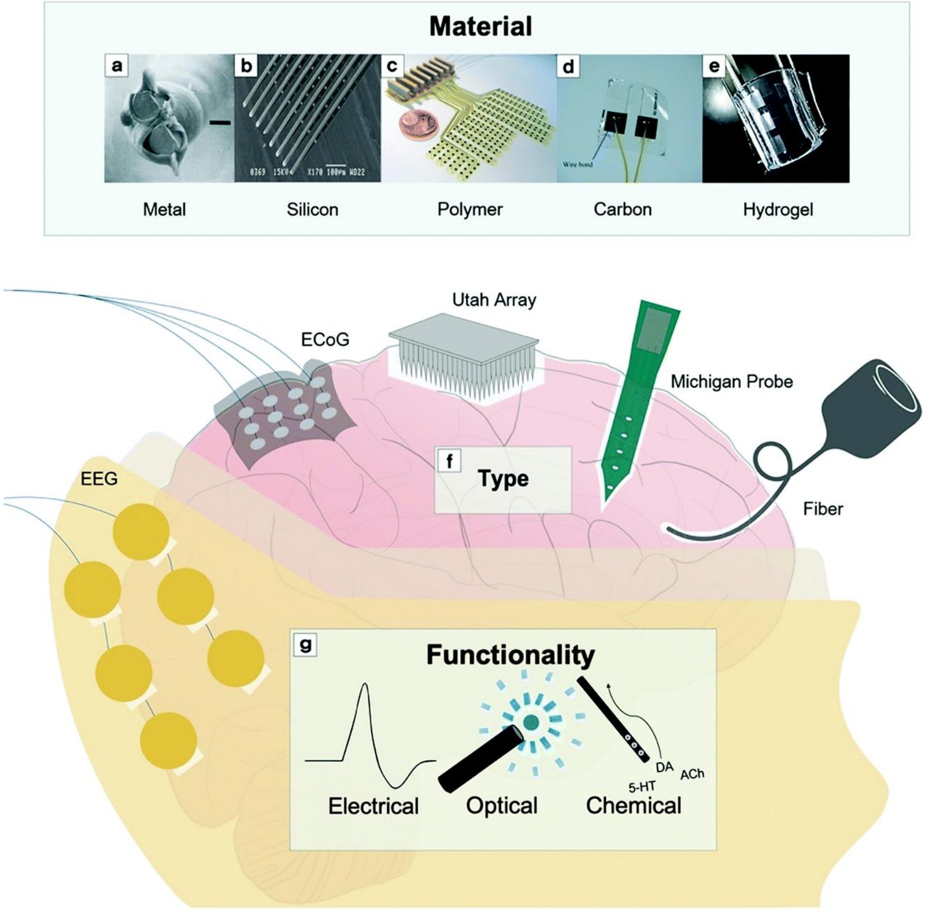




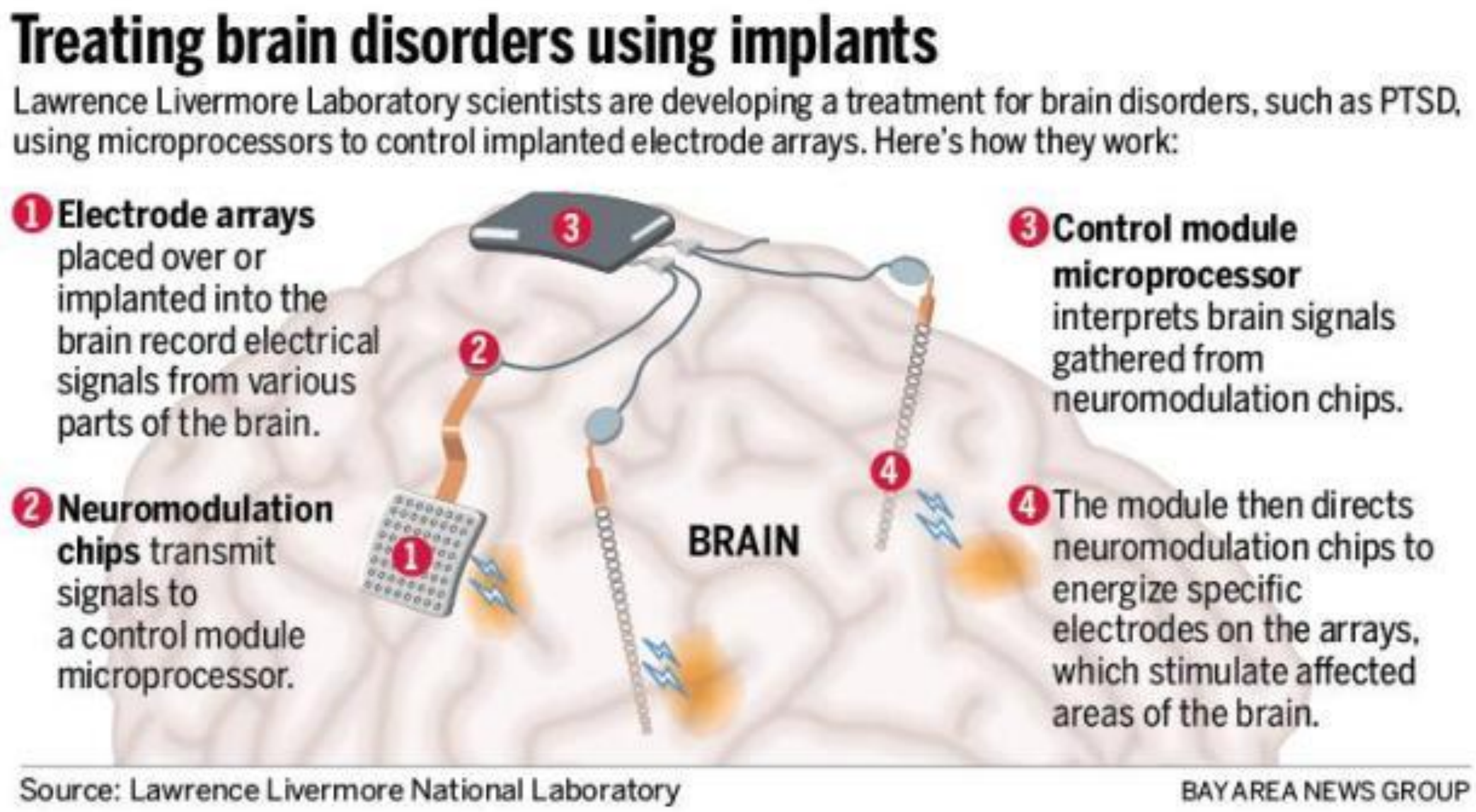
Implantable biosensors for physical sensing

Such a system could monitor brain activity through neural recording and respond to the brain's subjective intentions or objective events, directly or indirectly, until the brain returns to its regular status.

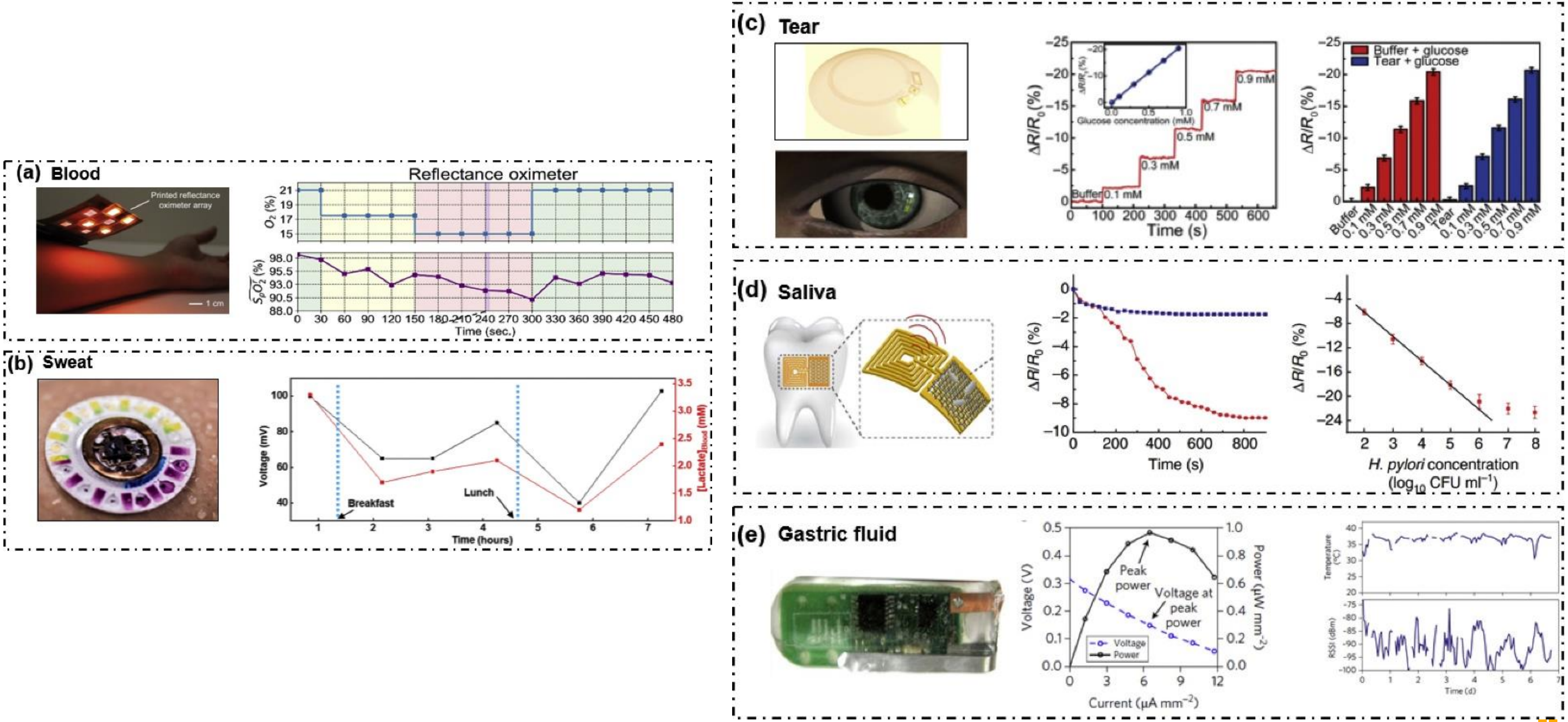




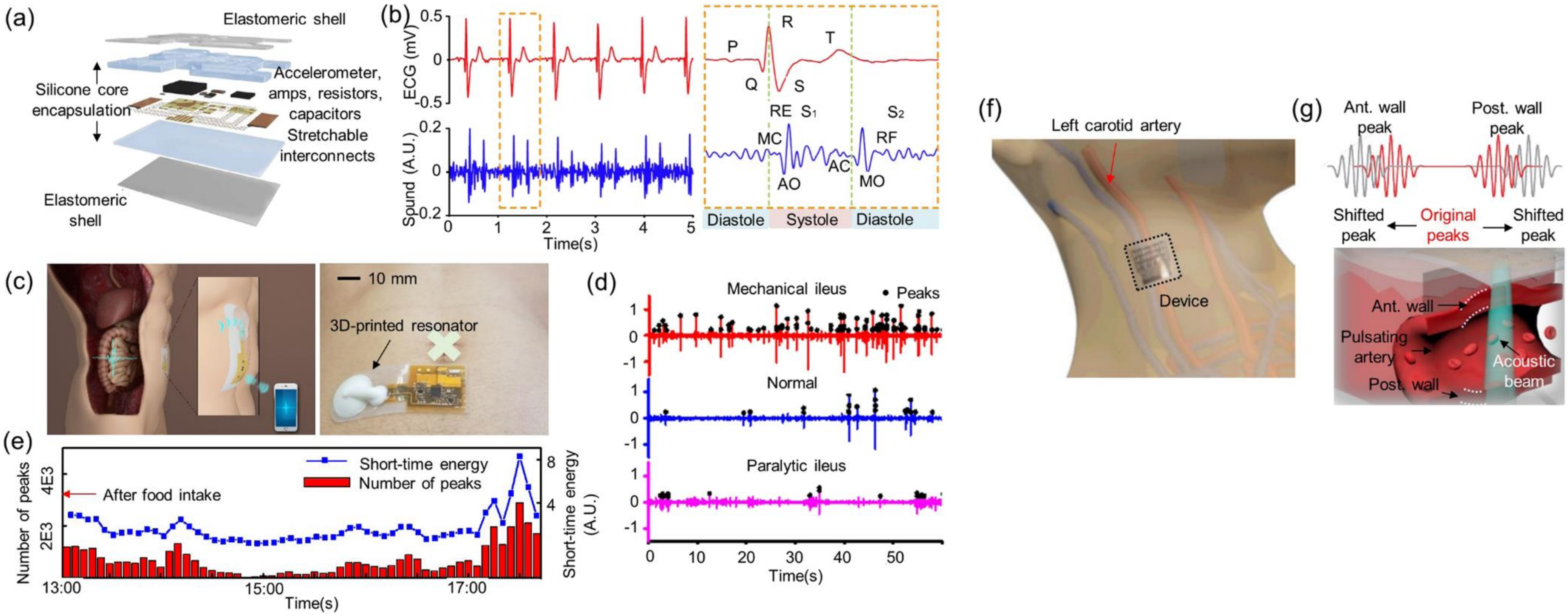
Implantable biosensors for physical sensing



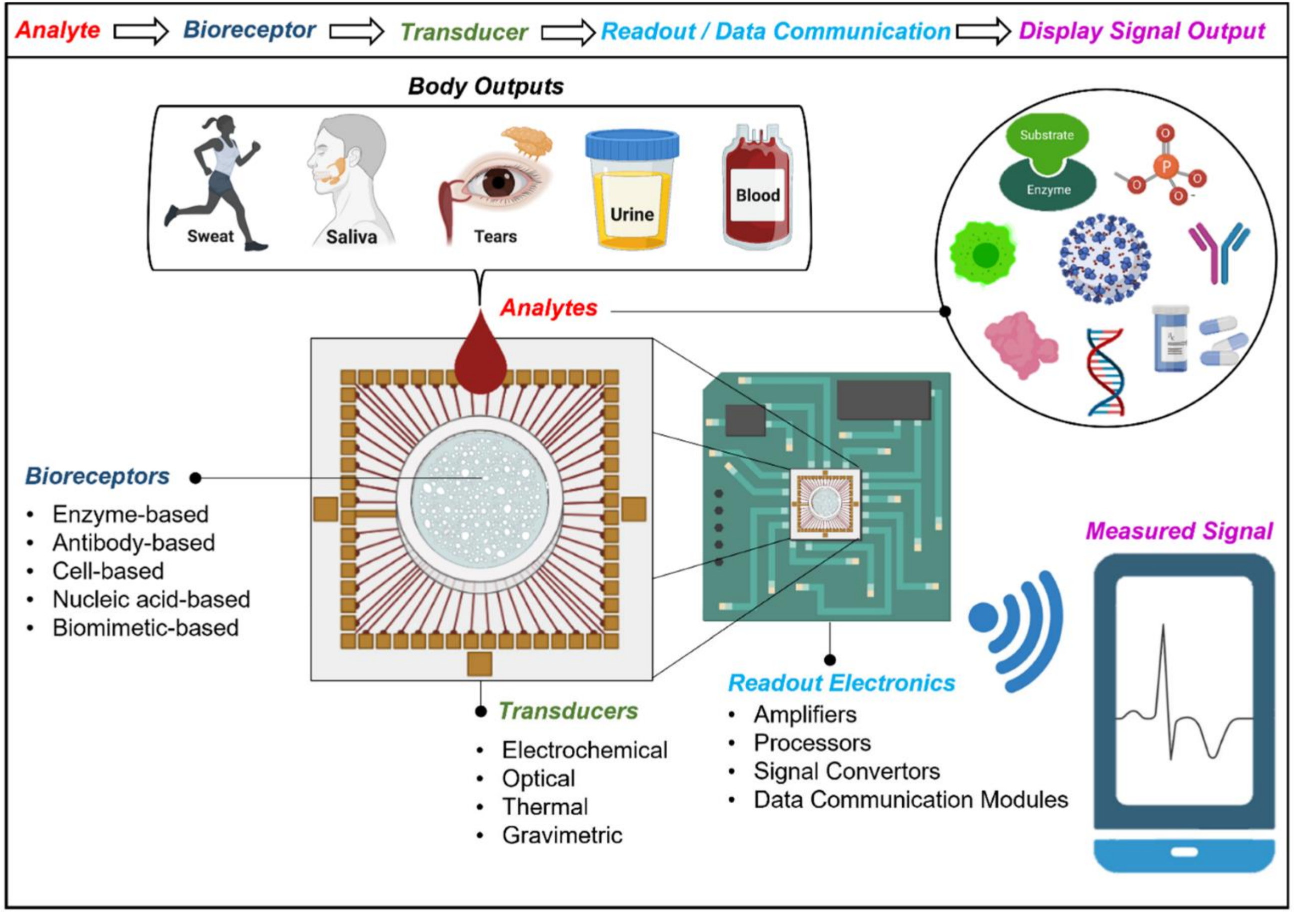
Applications of Optical Biosensors with Body Fluids



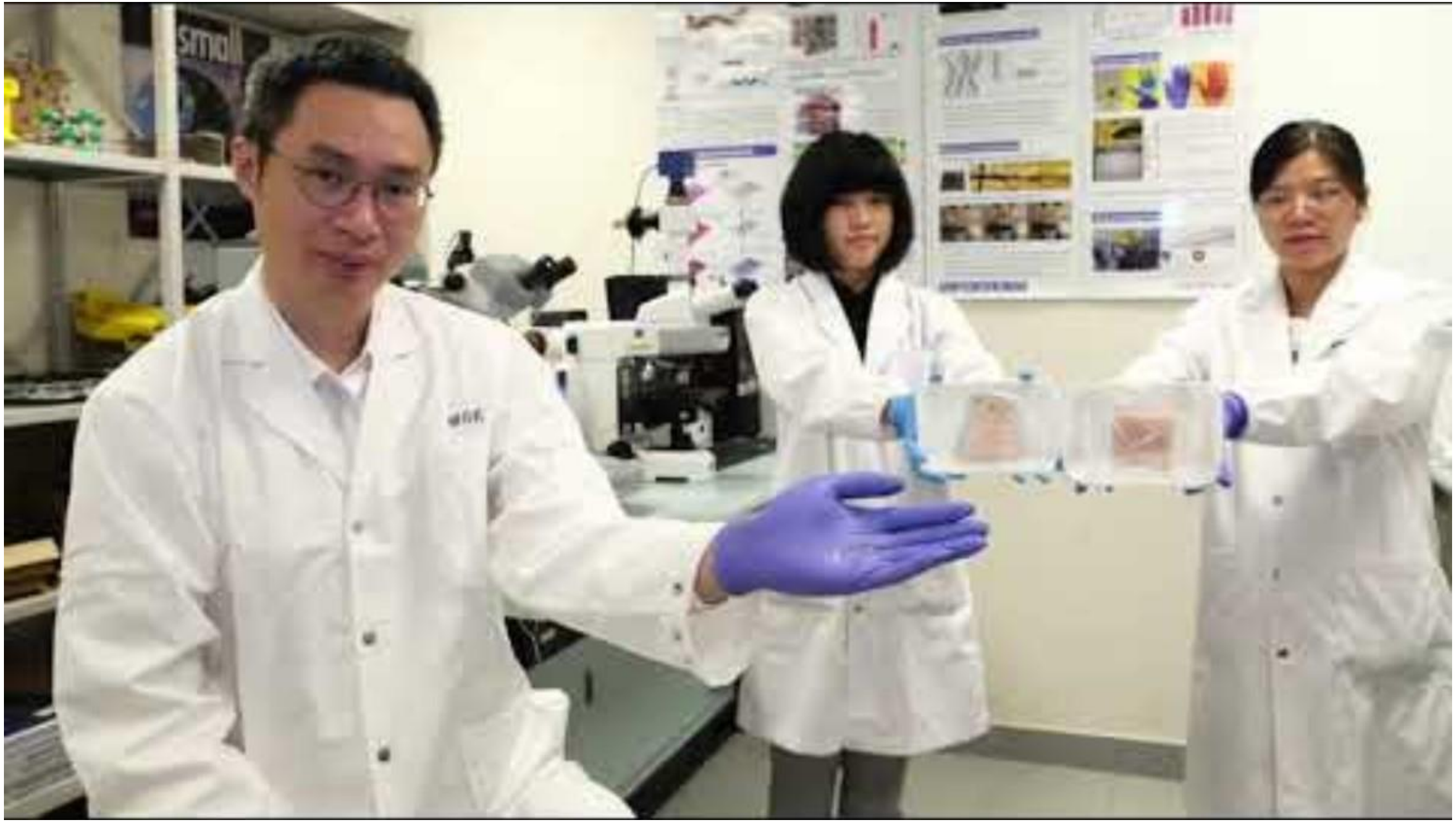
Flexible acoustic sensors and ultrasound devices



Applications of Biosensors



Examples of AI-Assisted Biosensor (optics /electronics)



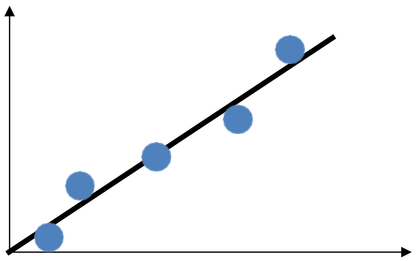
5

PART FOUR

SAMPLE EXAMS

Question: (15 points)
1. What are the main components of a biosensor?
2. Please draw the structure of a biosensor and describe the functions of each component. Give two examples for each component.

Question: (10 points)
For any biosensor, both sensitivty and selectivity are important.
(a) What is sensitivity? (7pt)
(b) What is selectivity? (7pt)
(c) Calculate the limit of detection for the data given.



An ultrasound imaging system has a detection sensitivity of 120 dB (10^{-6}). Assuming that the tissue is homogeneous, the attenuation coefficient of the tissue sample is 0.4 $cm^{-1} \cdot MHz^{-1}$ and the velocity of the ultrasound in the tissue sample is 1,540 m/s. The required penetration depth is 10 cm in the tissue sample.

(i) Calculate the pulse repetition rate for optimal imaging speed without reducing the depth imaging range.

(2 Marks)

(ii) Estimate the transverse resolution with numerical aperture of 0.1.

(2 Marks)

(iii) Estimate the axial resolution assuming 2 wave cycles (periods) within a pulse.

(2 Marks)

(iv) Compare the imaging performances between B-mode ultrasound and optical microscopy. Explain the theoretical basis of the differences between them.

(4 Marks)

Biopotentials

(a) List the 3 common type of sources of biopotential electrode sensor and briefly mention what signals or activities it is measuring in human body, respectively.

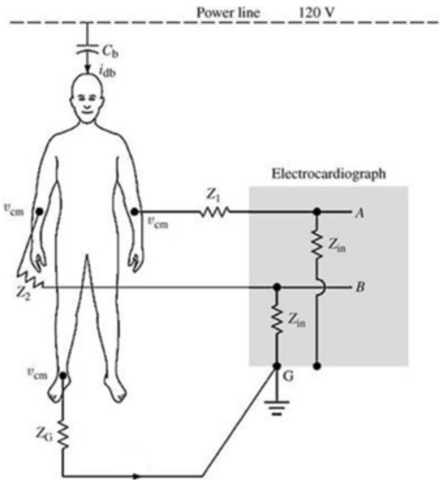
(5 Marks)

(b) A student attempts to measure his own ECG on an oscilloscope having a differential input. Draw the equivalent biopotential circuit for the Figure 4 below. $Z_{in} = 1\ M\Omega$; $Z_1 = 20k\Omega$; $Z_G = 30k\ \Omega$; $i_{db} = 0.5\ \mu A$.

(5 Marks)

(c) Calculate the biopotential difference across A-B.

(5 Marks)



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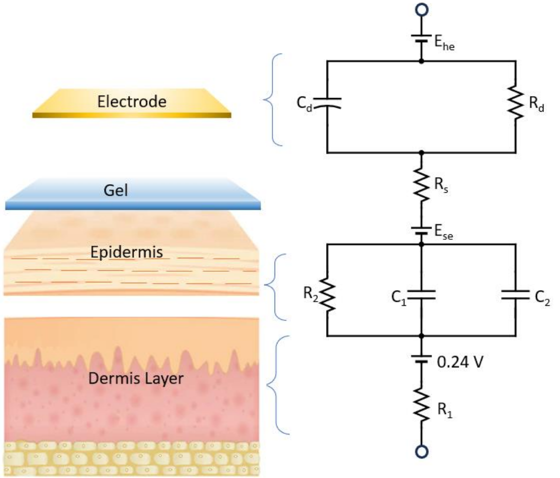
2. Figure 2 shows the equivalent circuit of a biopotential electrode attached on human skin interface to measure its electrical signals. The test consists of measuring the magnitude of the impedance between the electrodes as a function of frequency via low-level sinusoidal excitation so that the impedances are not affected by the current crossing the electrode–electrolyte interface. The impedance of the human blood or other noise is small enough to be neglected.

(a) What is the impedance Z at the electrode-human interface and its magnitude Z $(j\omega)$ as a function of radial frequency ω? (5 Marks)

(b) What are the minimum and maximum of this magnitude that can be measured? (5 Marks)

(c) Sketch a Bode plot of the impedance between the electrodes over a frequency range of f=1Hz to f=100,000 Hz. (5 Marks)

(d) For a fatty patient, a higher resistance of 1500Ω is measured in his dermis layer, calculate the magnitude of skin tissue impedance under frequency of 60 Hz. (5 Marks)



Question: (15 points)

a) Describe the working principles of the following optical biosensing techniques: surface plasmon resonance, fluorescence, and Raman spectroscopy. (pick 2)

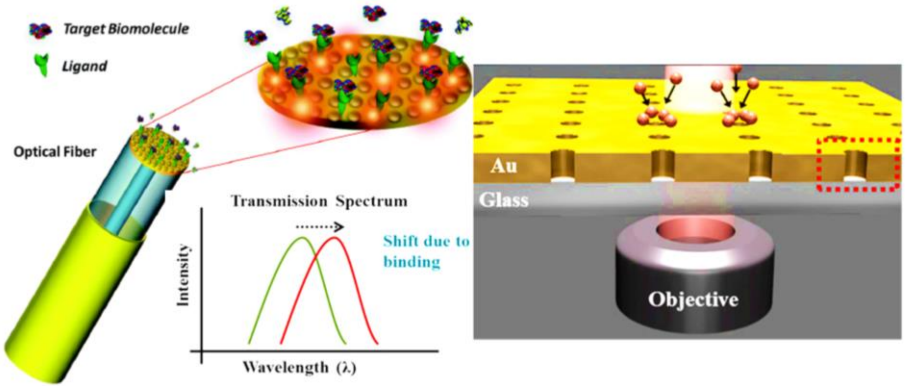
b) In an ellipsometry experiment, a substrate adsorbs immunoglobulin G increasing the film thickness by 5 nm. Assuming that the refractive index of the film is 1.52, refractive index of the medium is 1.33 and refractive index increment is 2 x 10^{-7} cm^2/mg, calculate the surface concentration of the attached immunoglobulin G?

15 points

Fiber sensors are common tools for measuring human tissue conditions by taking advantage of total internal reflection between the skin and fiber surface. Figure X shows the structure of fiber sensor with a fiber core, cladding layer surrounded by human tissue. The right panel shows the enlarge structure where the refractive index of fiber core, n_{core} = 1.6. The optical signals were then collected by a spectrometer with a grating of resolving power of 500.

(a) What is the minimum incident angle θ_1 to satisfy total internal reflection at skin/fiber cladding interface? Assume refractive index of tissue n_{tissue} is 1.38 for healthy patients.

(b) Assume the incident angle θ_1 changes from θ_1 =48o to 52 o, what is the minimum range of tissue refractive index n_{tissue} that can be detected based on total internal reflection?



Biomedical imaging technologies and systems.

1. The most common magnetic resonance imaging (MRI) sequences are T_1 -weighted and T_2 -weighted scans. At equilibrium, the external magnetic field B_0 and the net magnetization vector are both along the Z axis. Explain precession and the working principle of T_2 – weighted contrast. Show how the transverse magnetization changes over time.

(6 Marks)

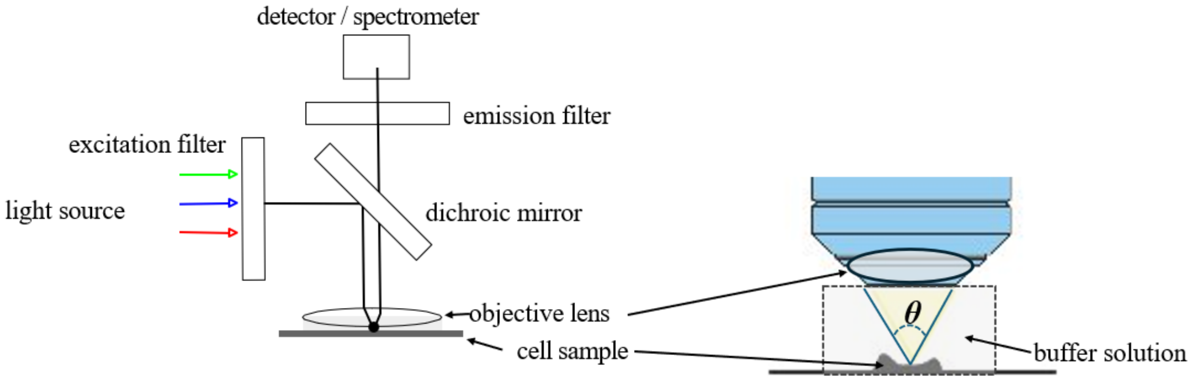
2. COVID-19 viral particles are around 150 nm micrometer in diameter. Discuss the possible range of wavelength and numerical aperture required for resolving individual viral particles using a wide-field microscope. Choices of embedding medium are air, water, and oil.

4. Marks)

1. Figure 1 shows an example of a fluorescence microscope imaging system, where a biological cell is excited by light passing through a set of filters then into the objective with a full convergence angle $\theta_1 = 60°$. The inset shows that the objective is formed by a focusing lens with refractive index of n_{lens}=1.6 and the sample is immersed in a buffer solution with refractive index of $n_{solution}$=1.4. The cell is labeled with a fluorescent dye which absorbs UV light and emits red fluorescence.

(a) Calculate the spatial resolution of an optical microscope using an excitation light with single photon energy of 3.26 eV. What is the resolution when excitation light is 1050 nm?

(b) Calculate the depth of focus (axial resolution) of the objective lenses if the magnification (M) is 10X.



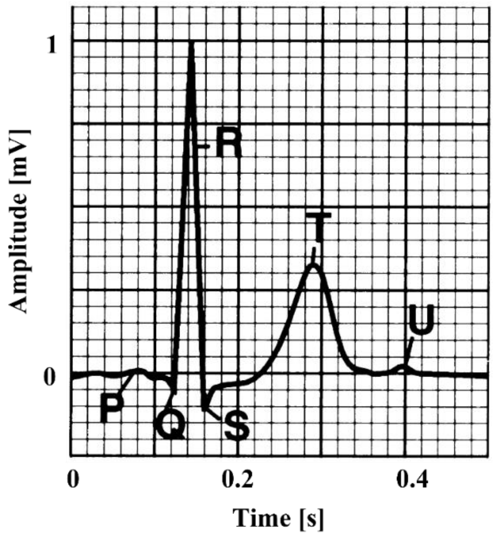
1. Given an Electrocardiography (ECG) signal captured by a clinical monitor as shown in the image in Figure 4:

(a) What is the minimum sampling frequency that a microcontroller unit (MCU) is required to accurately capture the QRS complex?

(b) If the MCU operates at a logic voltage level of 1.8V, what is the minimum analog to digital converter (ADC) resolution required to capture the QRS complex with sufficient accuracy?

(c) For an MCU with 32KB of flash program memory, 1KB Electrically Erasable Programmable Read-Only Memory (EEPROM), and 2KB internal (Static random-access memory) SRAM, and assuming a moving average filter is used to smooth the ECG signal, what is the maximum filter size that can be supported if data is stored in floating-point format? Assume the sampling frequency is 250 Hz.

(d) What is the maximum allowable moving window size (moving speed) to maintain the key features of the QRS complex?



(5 Marks)

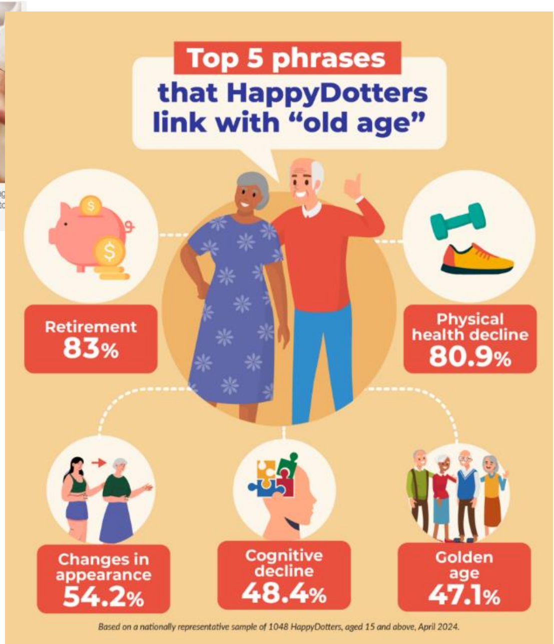
6

PART Five

PROJECTS

TOPIC

A smart device for ageing related diseases/ issues
A software platform for ageing related diseases/issues



Project should include:

- Single Project (1 person 1 submission)
- 1 PPT slides with recorded mp4. file uploaded.

- Background / Motivation
- State-or-art technologies- comparison
- Problem Statement (what are you trying to solve?)
- Proposed Technology as Solution
- Expected Outcome
- Conclusions & Limitations

- **PPT slides: 10+ slides (10% final grade)**
- **Recorded Presentation: limit 5-8 minutes (10% final grade)**
- **Due on Week 13. No late submissions accepted.**

THANKS FOR YOUR TIME