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DIPARTIMENTO DI ELETTRONICA,
INFORMAZIONE E BIOINGEGNERIA

The United Nations Agenda 2030: goals and the role of microsensors

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MEMS and Microsensors – M.Sc. in Electronics Engineering

Motivations and goals

- 17 sustainable development goals (SDGs):
  - Signed Sept 2015 by 193 countries of the United Nations.

Outline

- The context
  - United nations 2030 goals
  - Overview of sensors role within the goals

- Sustainable cities and communities
  - Facts
  - Case study: sensors for autonomous driving

- Good health and wellbeing
  - Facts
  - Case study: sensors for vestibular disease

- Industry innovation and infrastructures
  - Facts
  - Case study: sensors for predictive maintenance

The context

- The United Nations (UN) is an **intergovernmental organization** whose purposes are to **maintain international peace and security**, develop friendly relations among nations, achieve **international cooperation**, and be a centre for **harmonizing actions of nations**.
- It is the world's largest and most familiar international organization, with **193 member nations + 2 observers** (Holy See and Palestine).

- Objectives of **Agenda 2030**: change the world towards **sustainable development**.
  - An **action plan** for the planet, the people, and prosperity.
  - Pursuing the **peace**, **human rights** and **freedom** principles for the whole world, including women's emancipation.
  - Major challenge: **eradicate poverty** in all its aspects. Poverty is at the **root** of **wars**, **climate changes** and **freedom** limitations.

General aims

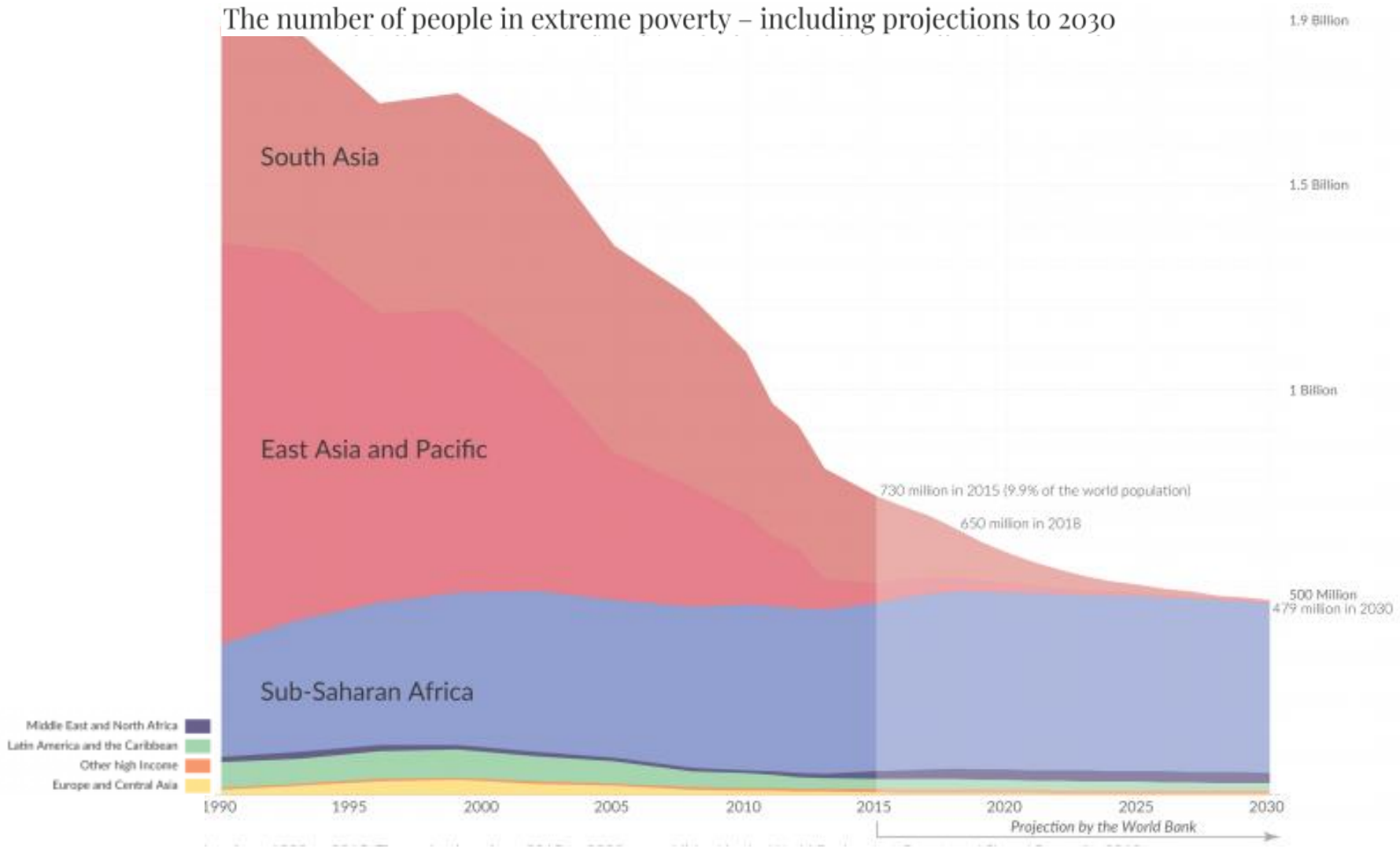
- People
  - **Stop poverty and hunger** and ensure **dignity** for every single human being
- Planet
  - **Protect Earth** degradation through conscoius, sustainable use of resources
- Prosperity
  - Act for a **harmonic economical progress** for all human beings
- Peace
  - Promote **peaceful societies** free from fear and violence. There is no sustainable future without peace and viceversa
- Collaboration
  - A **global collaboration** shall be stimulated through a spirit of solidarity between countries

Successes and failures

- UN peacekeeping missions operate in the **world most dangerous environments**, dealing with **conflicts** or their **aftermath**, which others cannot or will not address.

- Achieved peacekeeping:
  - UN helped **end conflicts** and **foster reconciliation** by conducting **successful peacekeeping operations in dozens of countries**, including Cambodia, El Salvador, Guatemala, Mozambique, Namibia and Tajikistan.
  - UN peacekeeping also **made a real difference** in other places with recent or **on-going operations** such as Sierra Leone, Burundi, Côte d'Ivoire, Timor-Leste, Liberia, Haiti and Kosovo. UN operations **supported political transitions** and helped countries to close the chapter of conflict and open a path to normal development.
- Instances where UN peacekeeping has been challenged:
  - for instance in Somalia, Rwanda and the former Yugoslavia in the early 1990s. These setbacks provided important lessons for the international community when deciding how and when to deploy and support UN peacekeeping.

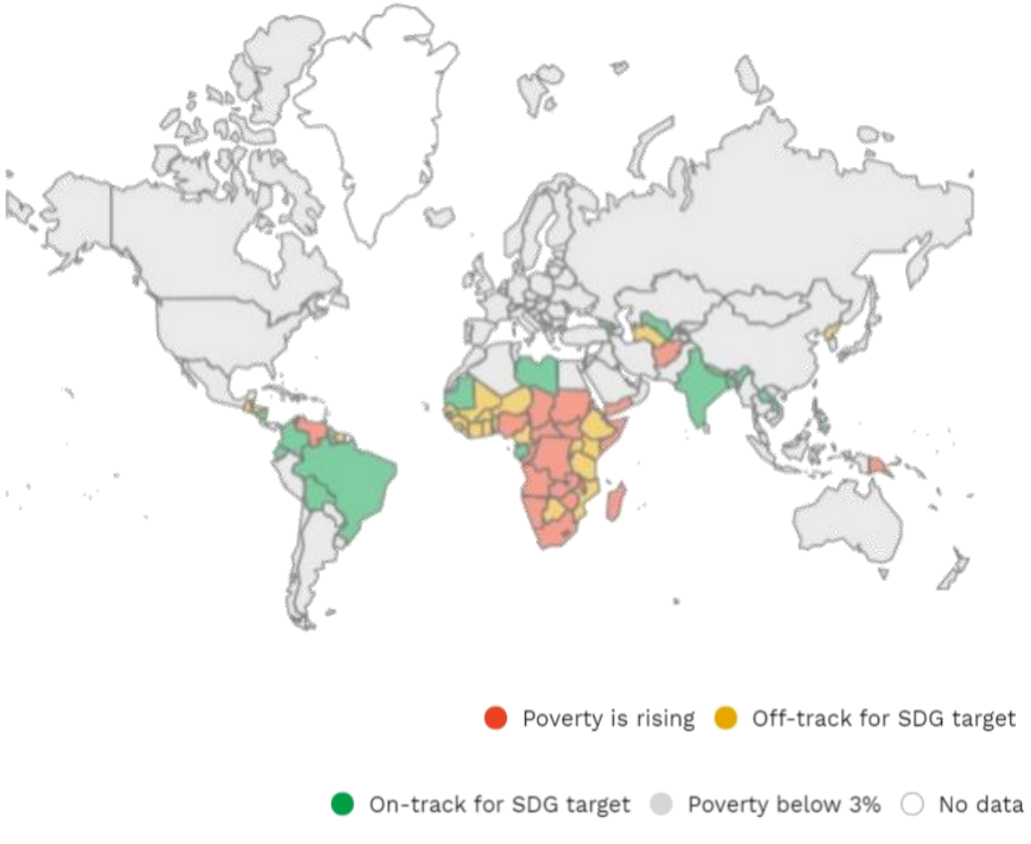
Our world, today: challenges (1)



- Billions of human beings are still in extreme poverty and non dignitous conditions.
- Disparity and inequality is rising from country to country and within individual countries.

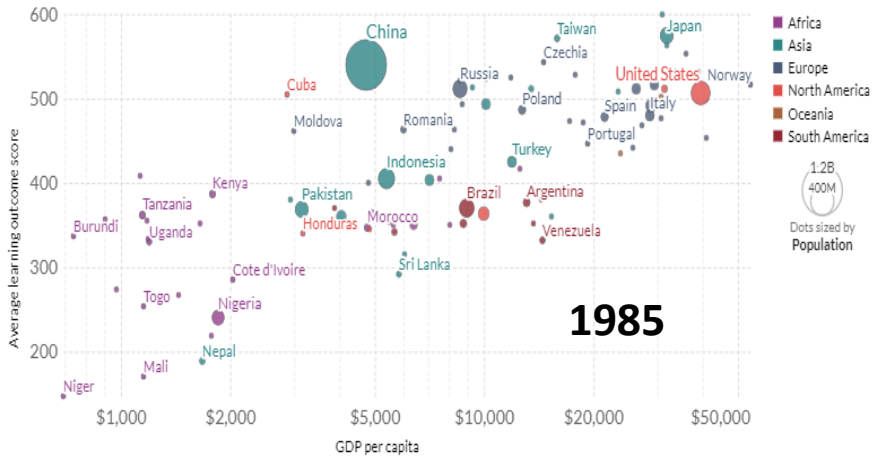
Our world, today: challenges (2)

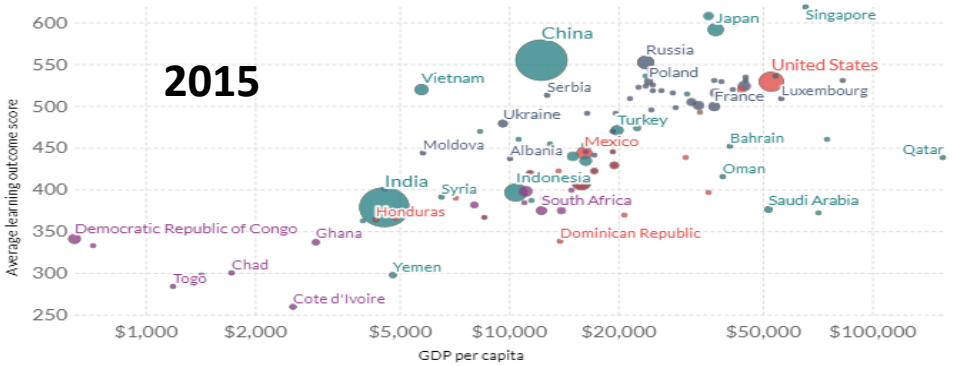
- Additional challenges accompanying poverty are represented by
  - Gender disparity
  - **Unemployment**
  - **Health** threats
  - Natural **disasters**
  - **Wars** and terrorism
  - Insufficient **natural resources**
  - **Desertification** and dryness
  - Loss of **biodiversity**
  - Global **warming** and rising sea levels



Our world, today: opportunities

- At the same time, it is an **era of opportunities**:
  - **People awareness** on most of these issues is very high
  - **Young people** are now sensitive to these issues (Greta generation)
  - **Technology** has made **access to knowledge and education** easier





- **Technology** has made **progress faster**

Different scenarios:
Ivory coast,
Indonesia,
Mexico

- All these goals shall now be transferred to all countries

Actuation means

- Total committment from United Nations
- **Money** and **technology** transfer to **countries in need**
- Responsibility of each country
  - Supporting countries committ
    - to use **0.7% of GDP to support the program**
    - To use **0.15% of GDP** for **direct support to countries in need**
  - Developing countries committ to **adhere to the program** in using these resources
- Fundamental direct or indirect role of:
  - individual countries, in actuating laws and terms for the committment above
  - international financial institutions
  - non governmental organizations

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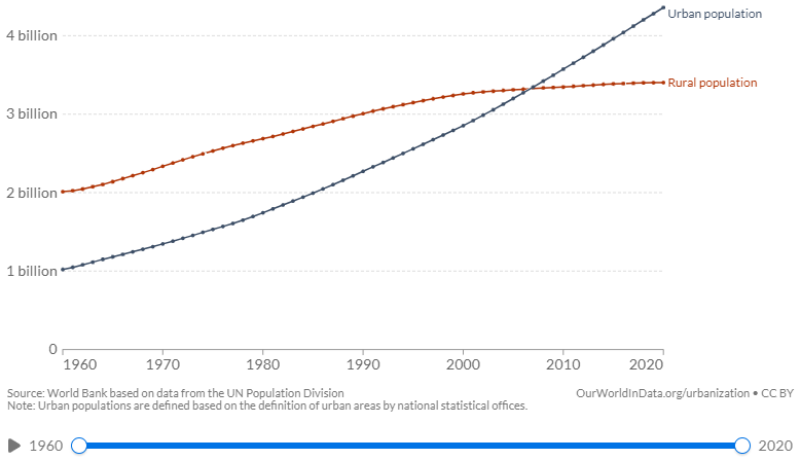
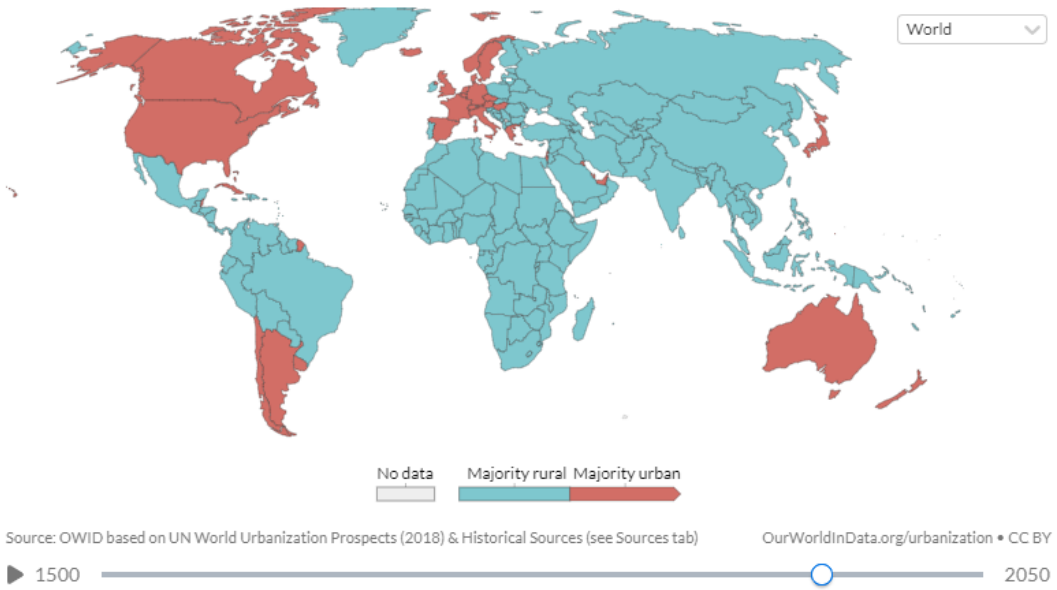
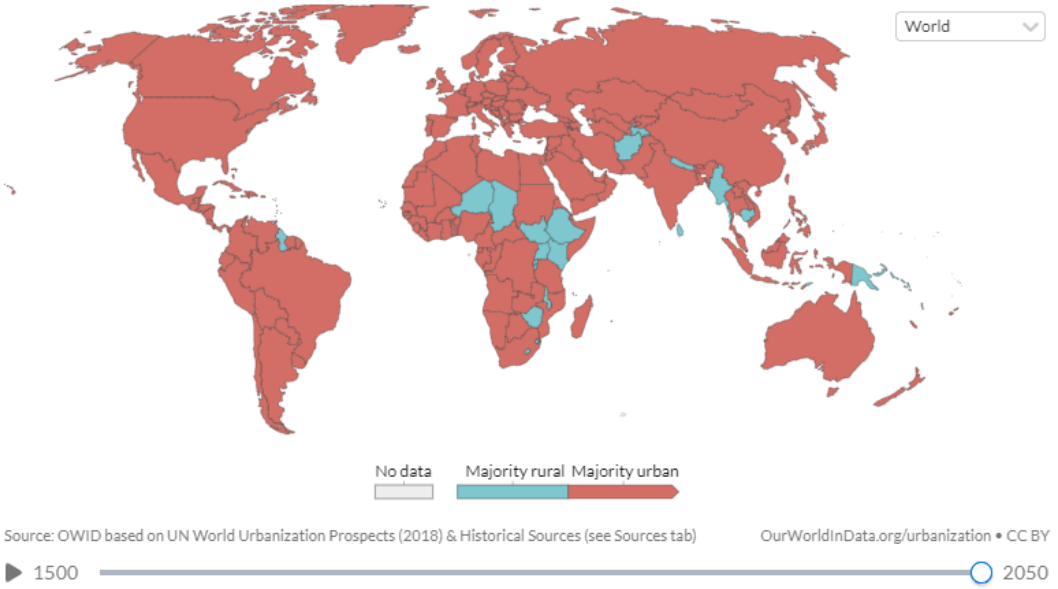
Facts: urbanization

- 2 people over 3 living in urban areas by 2040



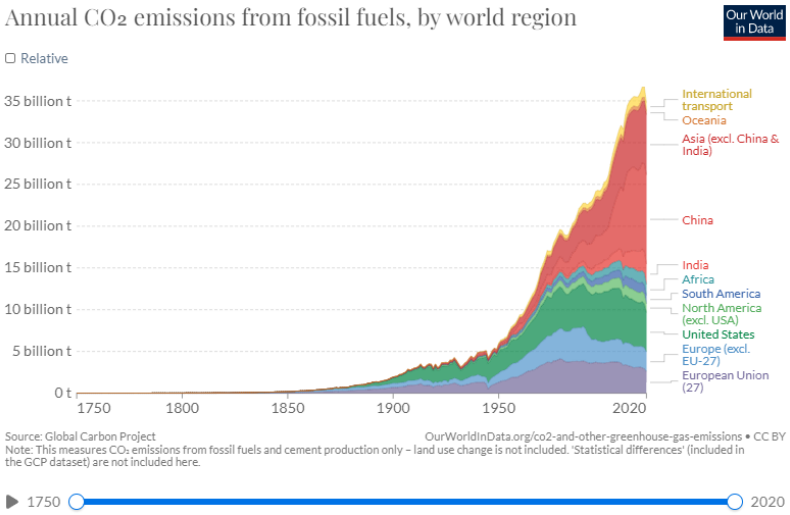


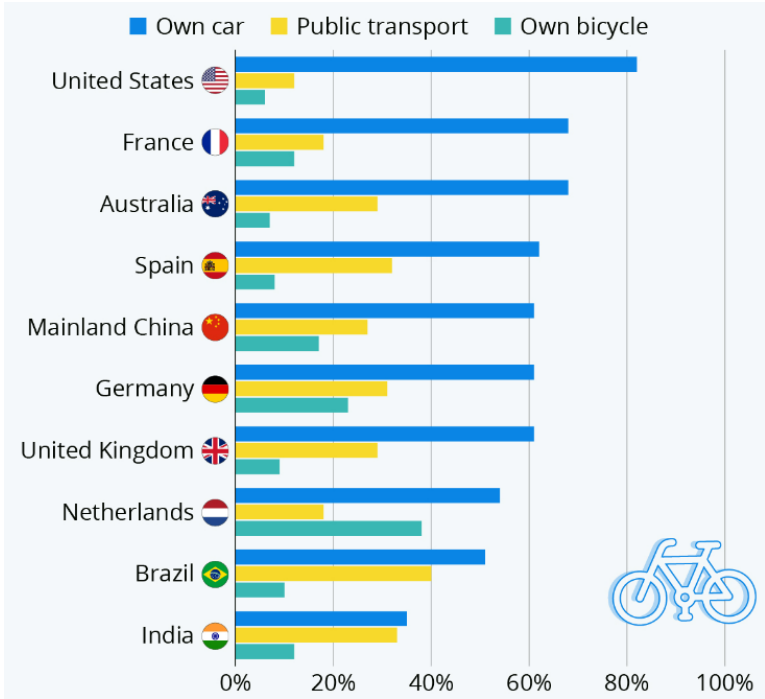
- Importance of sustainable cities (and communities) becomes mandatory for 100% of human population (mostly impacted are non-urban!)



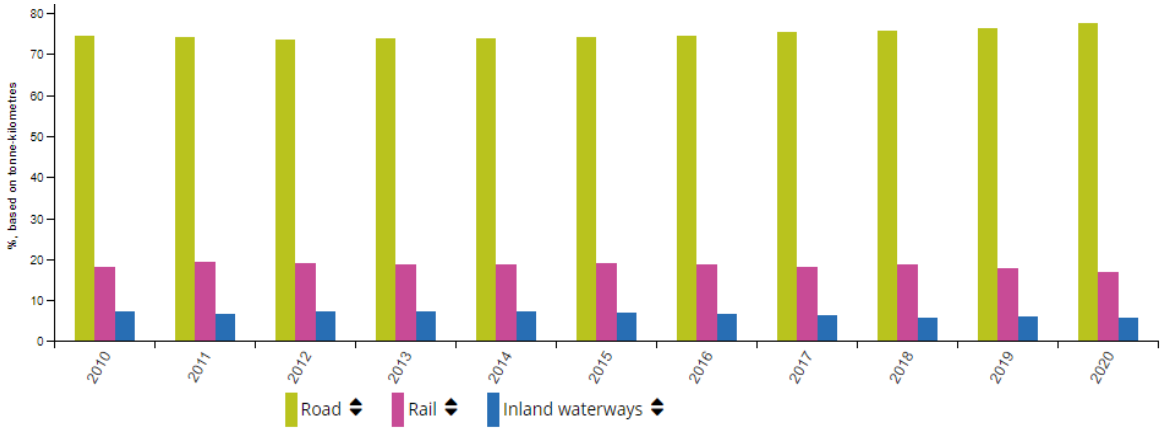
Facts: urban and non-urban transport

- People commute much more by own cars than by public transport.





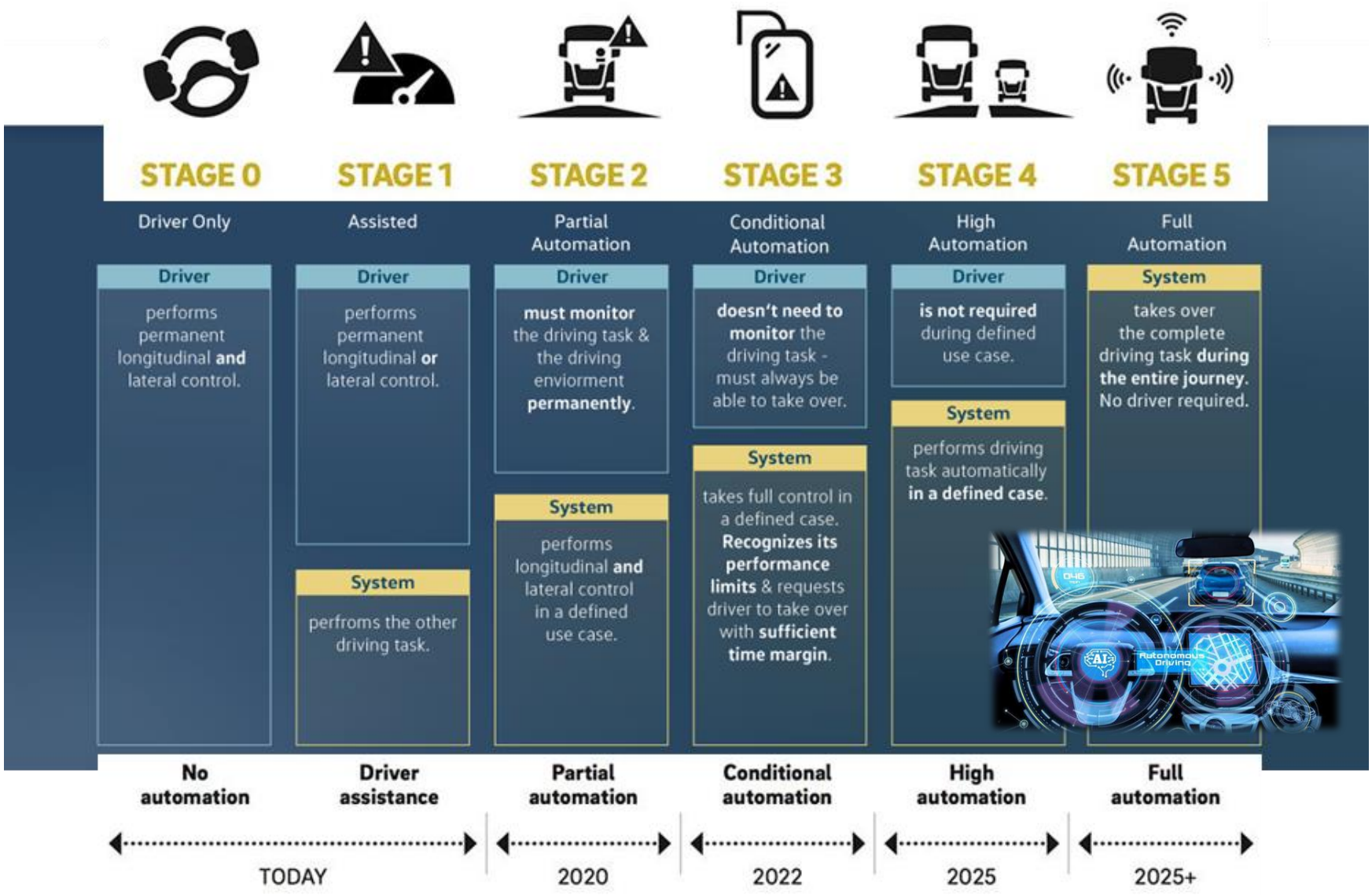
- Non aerial freight delivery occurs much more by road than by rail transport, even in suburban areas.



Advantages of autonomous driving

- Reducing accidents (costs), queues (costs), pollution
- Reducing travel time, pollution
- Optimizing speed vs infrastructure (reducing pollution)
- Reducing stress of drivers
- More time for extra-commuting life
- More efficiency at work without stressing commutes

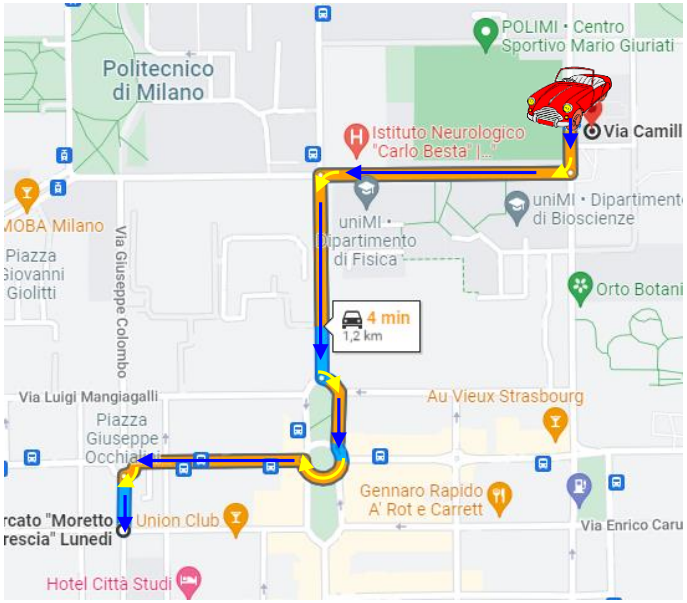
Roadmap towards autonomous driving



Motion sensors in autonomous vehicles

- The **most fundamental information** to sense for a vehicle is its own **position/motion**.

- Motion can be seen as a **combination of linear translation and rotation in a quasi 2-D plane**. Absolute **orientation** sensors, **acceleration** sensors and **angular rate** sensors can be used to retrieve the motion of a vehicle with an **accuracy** which – on short time intervals – is **much better than GPS**.



Accelerometers (linear acceleration)

Magnetometers (orientation)

Gyroscopes (angular velocity)

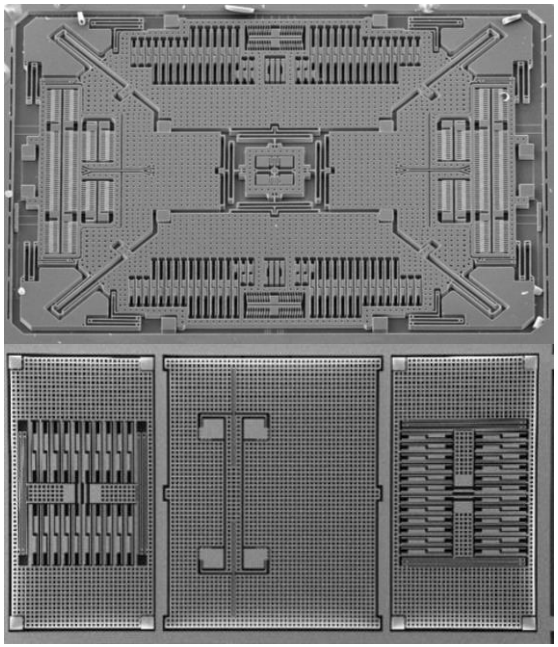
$$\theta = \theta_0 + \int_0^t \Omega(t)dt$$

$$x(t) = x_0 + \int_0^t v(t)dt = x_0 + \int_0^t \left[v_0 + \left(\int_0^t a(t)\,dt\right)\right] dt$$

Inertial Positioning

MEMS accelerometers, gyroscopes, magnetometers

- They will form the first half of the course topics, and we will study in details their sensor design, electronics design and system-level requirements for different applications.

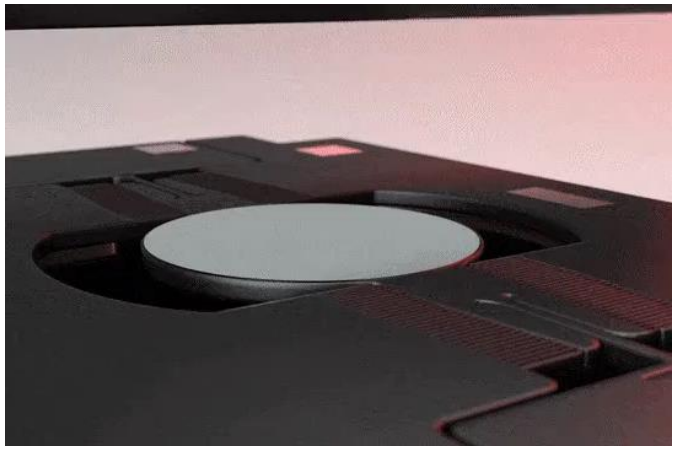


IMU

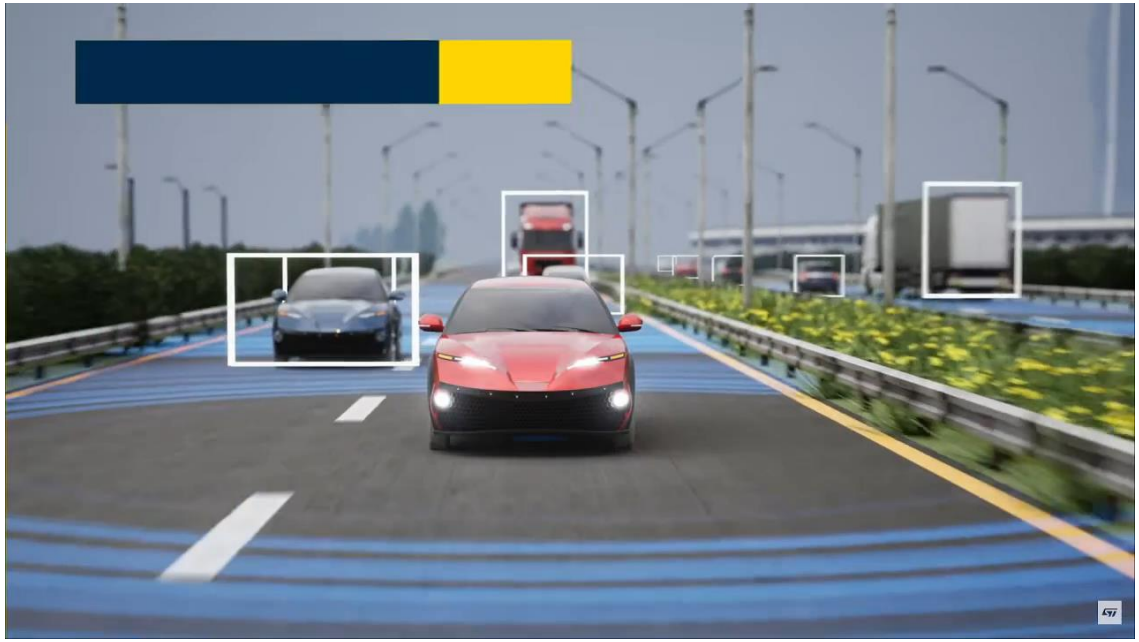
- We have plenty of theses in our laboratory on innovative sensors.

3D sensors in autonomous vehicles

- How to scan the environment?
  - generate a 2D laser beam scanning the environment
  - measure the time of flight (TOF) of reflected beams → this gives you the distance information

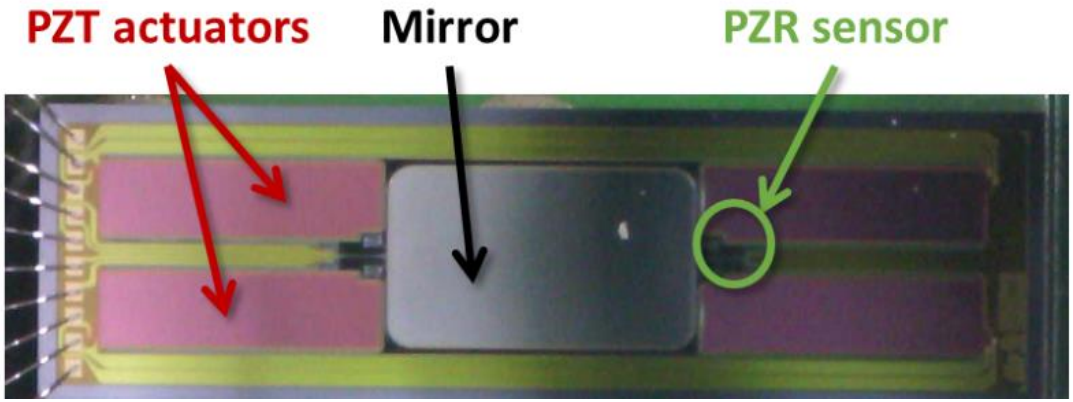


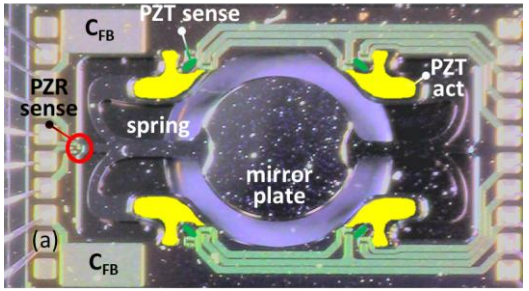
- MEMS micromirrors are used to generate the 2D beam profile and image sensors are used to sense the reflected beams → 3D image reconstruction!



MEMS micromirrors

- They represent one of the first emerging micro-actuator on the market. They are not strictly a topic of this course, but we have plenty of M.S. thesis in our laboratory on this topic.





- Key technological differences over inertial sensors:
  - Need for large tilt angles
    - No capacitive actuation (no small displacement possible), but use of piezoelectric actuation
  - Need for reflective surfaces
    - Thin Al coating deposited on the mirror surface

Camera sensors in autonomous vehicles

- Goal 1: see as the human eye sees…
  - Traditional RGB CMOS sensors (we'll study them during the course)
- Goal 2: see better than human eye does
  - Infrared cameras (dehazing, see beyond fog…)

- Parking, manoeuvring and assess the vehicle performance,
- Lane Departure Warning Systems
- Forward Collision Warning System
- Blind Spot Warning
- ADAS

Remark

- Most of the shown videos belong to high-tech companies and start-ups… plenty of innovation is pervading the field of microsensors and actuators for future, sustainable, technologies!

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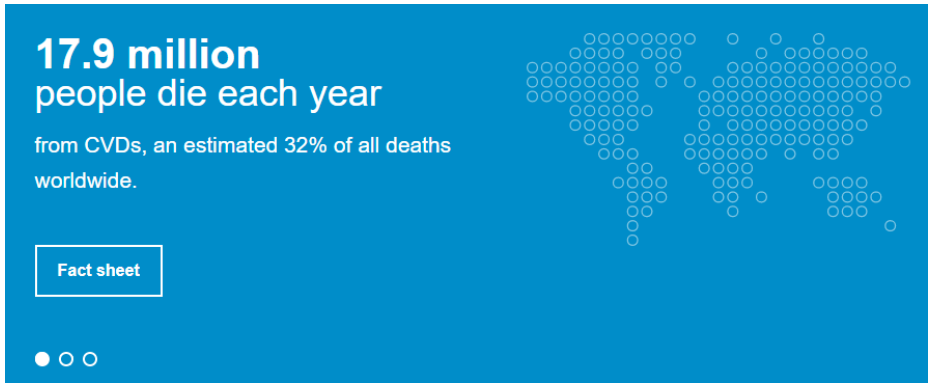
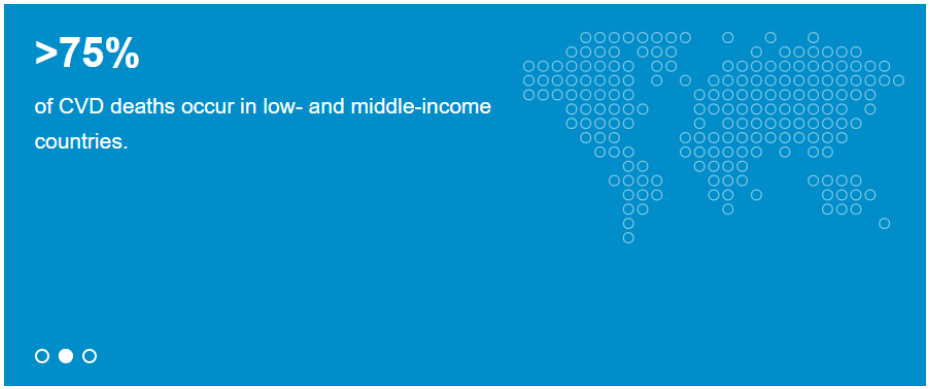
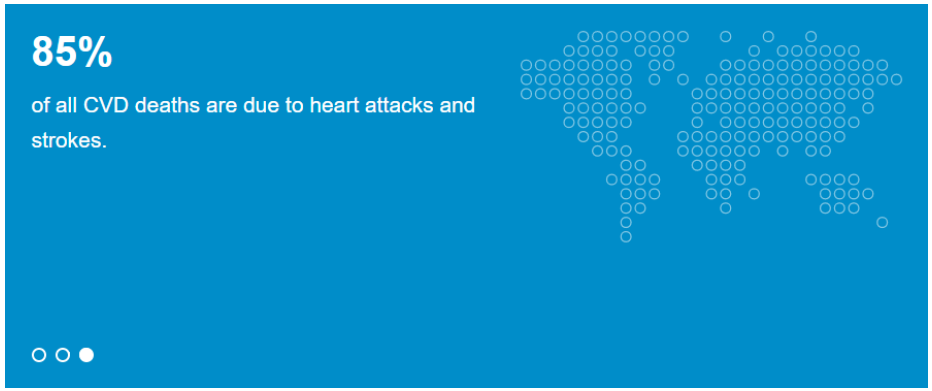
Facts (from WHO)



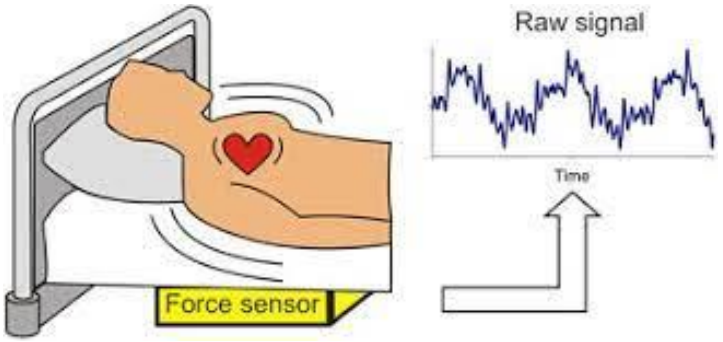




- Cardiovascular diseases (CVDs) are the leading cause of death globally.
- An estimated 17.9 million people died from CVDs in 2019, representing 32% of all global deaths. Of these deaths, 85% were due to heart attack and stroke.
- Over three quarters of CVD deaths take place in low- and middle-income countries.
- Out of the 17 million premature deaths (under the age of 70) due to noncommunicable diseases in 2019, 38% were caused by CVDs.
- Most cardiovascular diseases can be prevented by addressing behavioural risk factors such as tobacco use, unhealthy diet and obesity, physical inactivity and harmful use of alcohol.
- It is important to detect cardiovascular disease as early as possible so that management with counselling and medicines can begin.

Ballistocardiograph: what is it (from wiki)?

- The **ballistocardiograph** (BCG) is a measure of ballistic **forces** generated by the **heart**.
- The **movement of blood** through the aorta produces a **recoil**, moving the body with each heartbeat.



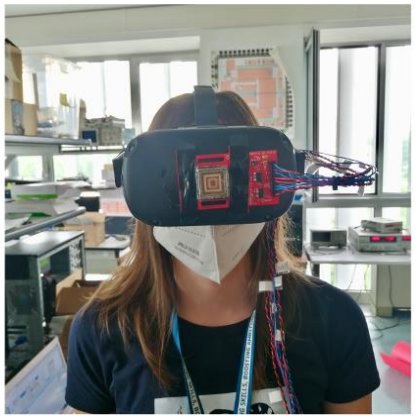
- As different parts of the aorta expand and contract, the body continues to move **downward and upward in a repeating pattern**. Accurate **inertial sensors** can **detect this tiny motion**.

Inertial sensors for ballistocardiography

Yaw

Pitch

Roll

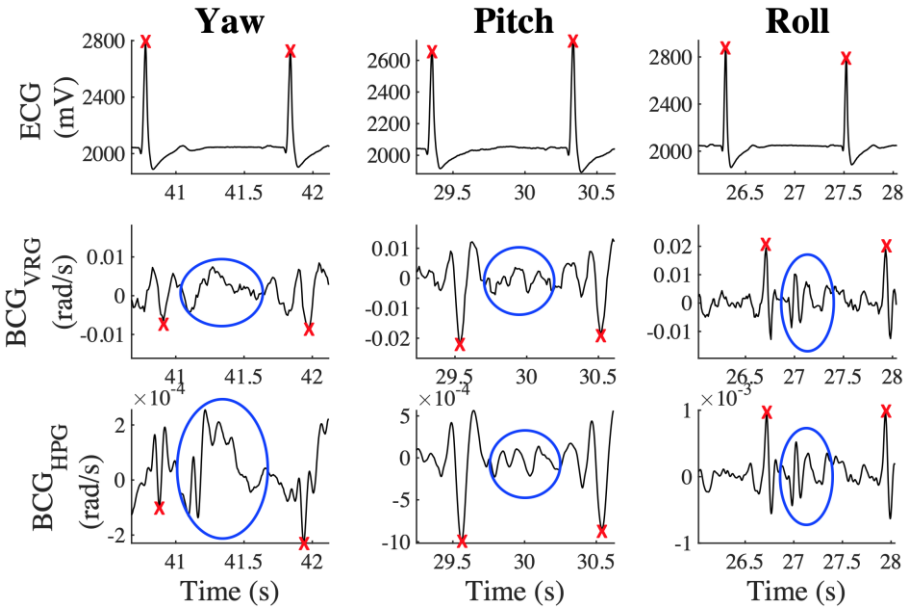


- Procedure can be simplified if inertial sensors have high sensitivity:
  - Let the person sit or lie down for about 30 s. Then begin recording.
  - Measure **head subtle rotation** induced by **blood sent back and forth to the head through the carotid arteries**...
  - Repeat the measurement for the three different angular rate directions...
  - Compare data with ECG...
- What do you expect?

Results

- BCG is a representation of **repetitive motions of the human body** arising from sudden blood ejection into the great vessels.
- It is **a vital sign in the 1–20 Hz range** caused by the mechanical movement of the heart. As it represents mechanical body motion, it is **different from the ECG** which is an electrical signal acquisition.

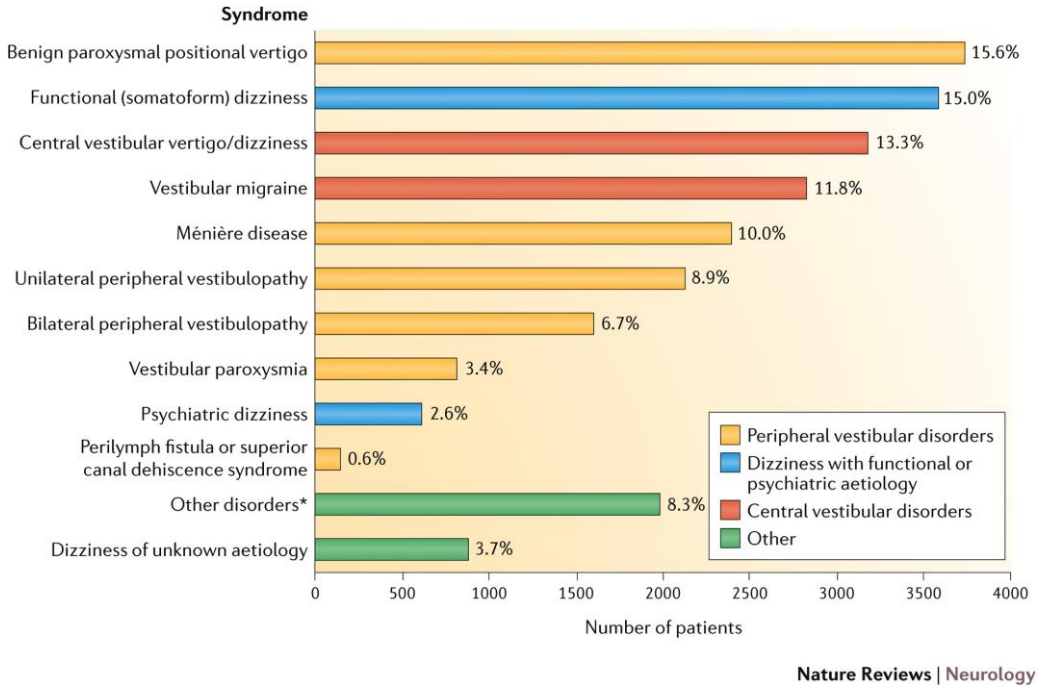
- Results:
  - Small delays between ECG peaks and BCG peaks… transit time of blood in the vessels
  - **Much denser information** between BCG peaks than ECG peaks…
    - analysis of **morphological characteristics** of the BCG signal, both during the systolic and diastolic phases of cardiac contraction, could be **correlated to alterations in the stroke volume**, which is a fundamental parameter for the assessment of **cardiovascular health**.



Facts

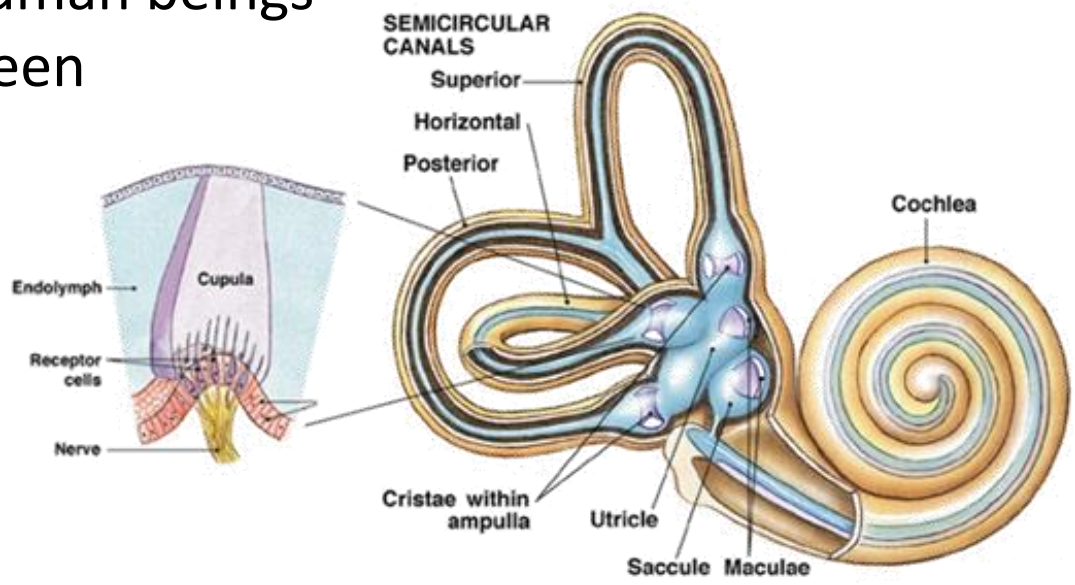
- Over **35% of adults aged 40 years and older** have had a **vestibular dysfunction** at some point in their lives.
  - If you are over 40 years old, you have a 1 in 3 chance of experiencing a balance problem at some point in your lifetime. A **balance disorder can be a life altering condition** if untreated.

- Typical symptoms:
  - **Dizziness**
  - Feeling **off-balance**
  - Feeling as if you are floating or as if the **world is spinning**
  - **Blurred vision**
  - Disorientation
  - Falling or stumbling

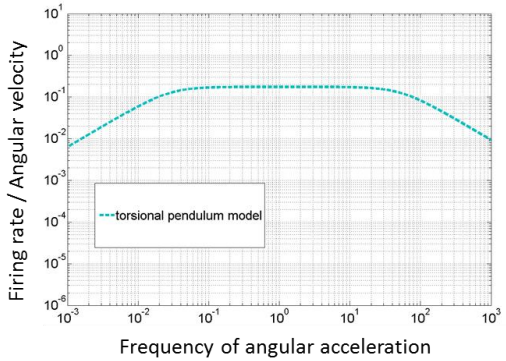


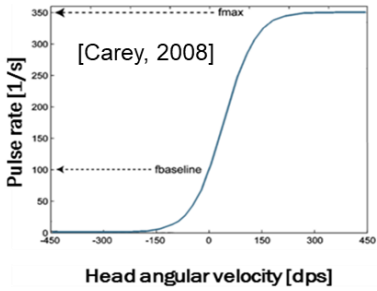
The vestibular system in human being

- The vestibular system in human beings **coordinates balance** between **equilibrium**, spatial **orientation**, body **dynamics** and some sensorial responses like vestibular-ocular reflexes.



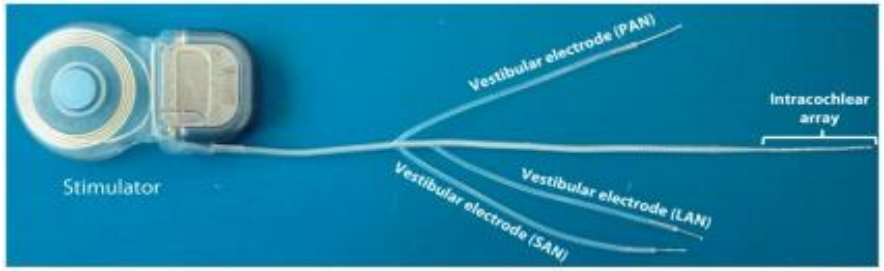
- Some diseases are caused by the **unhealthy operation** of the *sensors* in the vestibular system, which are the **semicircular canals**: these organs, at typical human motion frequencies (20 mHz to 50 Hz), behave as **angular rate sensors**.





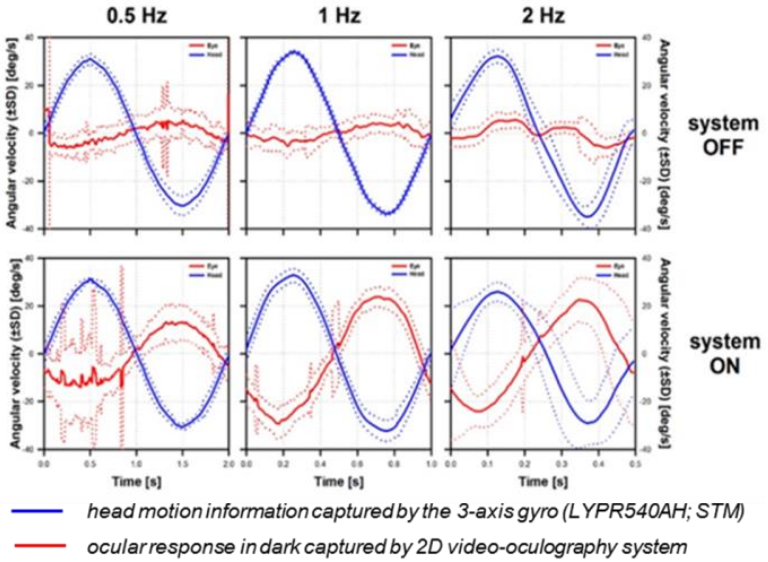
Gyroscopes for vestibular disease

- The possibility to **use MEMS gyroscopes** to restore vestibular functions was thus considered.

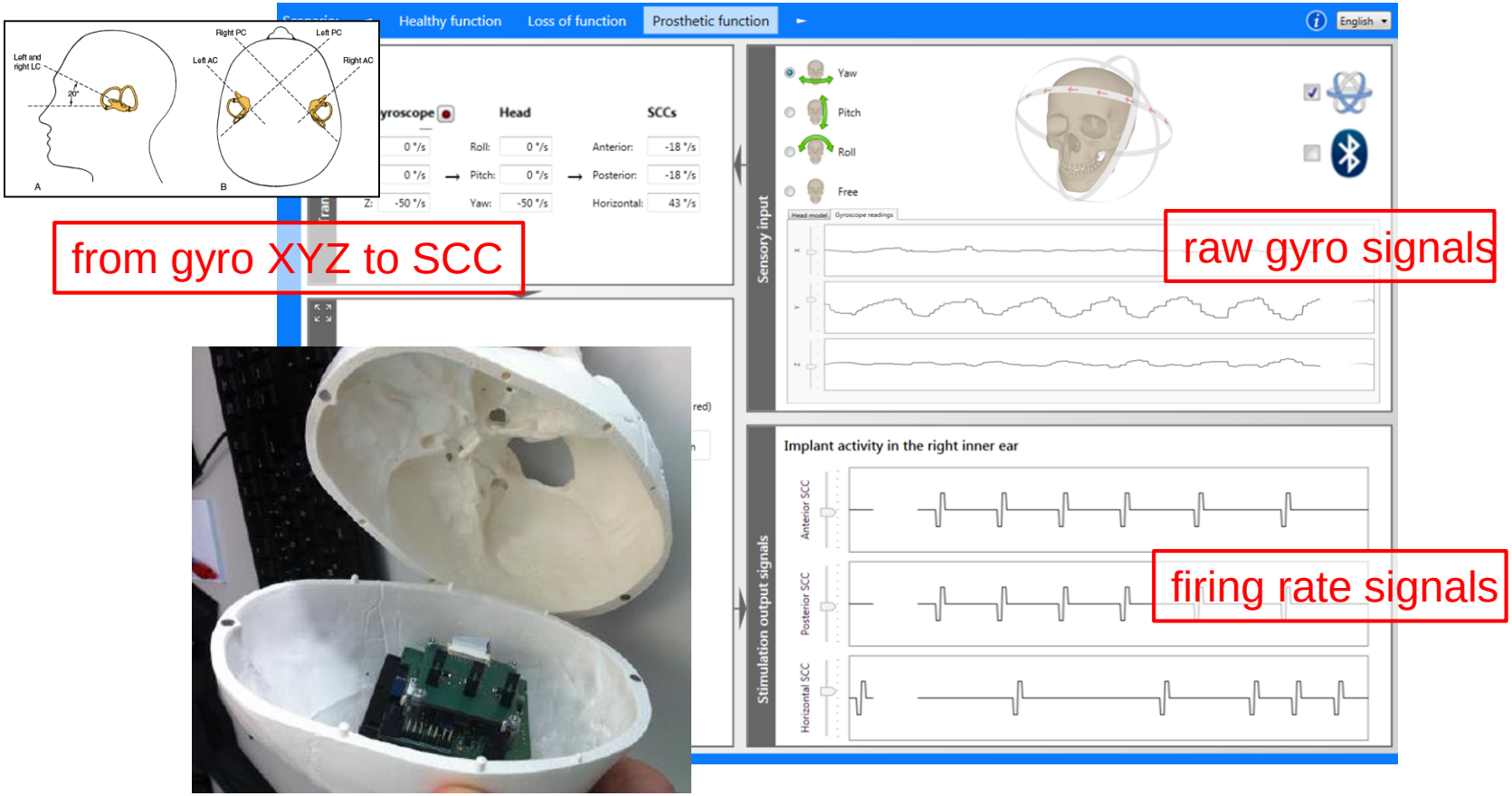


- First studies since early 2000s
  - responses on primates;
  - models for semi-circular canals;
  - artificial sensors to mimic natural organs.

- First test on humans since ca. 2014
  - non implanted gyro with vestibular electrodes;
  - **VOR restoration** (→ oscillopsia reduction) improvement in **gate stability**, 3x gain in **visual acuity** while walking



Roadmap


Healthy function
Loss of function
Prosthetic function
English
Head
SCCs
Roll:
Pitch:
Yaw:
Anterior:
Posterior:
Horizontal:
Yaw
Pitch
Roll
Free
Sensory input
Implant activity in the right inner ear
Anterior SCC
Posterior SCC
Horizontal SCC
Stimulation output signals
Right PC
Left PC
Left AC
Right AC
Left and right LC
A
B
from gyro XYZ to SCC
raw gyro signals
firing rate signals

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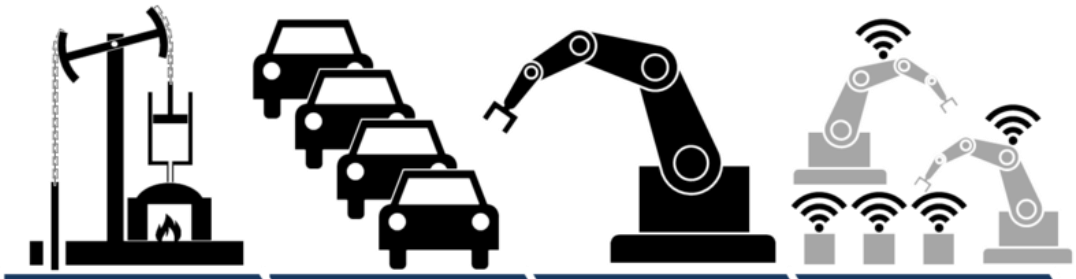
4th industrial revolution

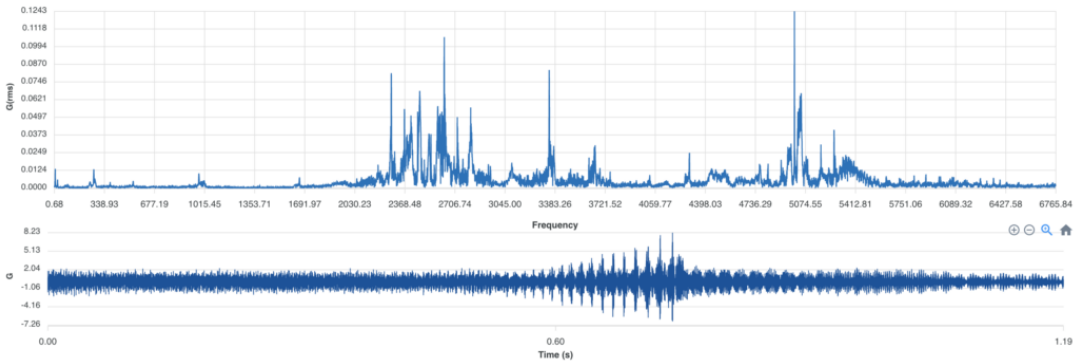


Smart sensors are enablers for the fourth industrial revolution

Plenty of applications in the industrial field

- 4th industrial revolution means using **IoT-connected equipment** to share **real-time information on the status of the machineries**.

- The **status** can be **monitored by smart sensors**, to detect not only the **environmental conditions** (temperature, pressure, humidity) but also some specific **operation parameters**, like motion of robotic arms, presence of anomalous vibrations, automatic detection of the presence of an operator…
  - such functionalities demand **robust inertial sensors** and **imaging sensors**.



Case study: predictive maintenance

Monitoring sensor output signals over a period of time can offer insights into equipment failure. From bearing vibration to rising temperatures, as properties change, the decline in performance or need for part replacement can be predicted to avoid catastrophic failure, downtime, and cost.

For industrial condition monitoring and predictive maintenance applications vibration specification parameters are considered critical to ensure long-term, reliable, stable and accurate performance including: wide frequency response, measurement resolution, low drift, and operating temperature.

Required specs:

- Wide bandwidth range (up to 20 kHz)
- High robustness and stability over temperature
- High resolution
- Embedded data transmission for long intervals
- Embedded FFT functionalities and spurious peaks detection