SM 14/15 – T6
Sensing Technology

LCC, MIERSI

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U.PORTO

References

- Slides from Edward A. Lee & Sanjit Seshia, UC Berkeley, EECS 149 Fall 2013
  -
- Pedro Brandão, Sistemas Embutidos, DCC/FCUP
  - https://moodle.up.pt/course/view.php?id=3162

Reality

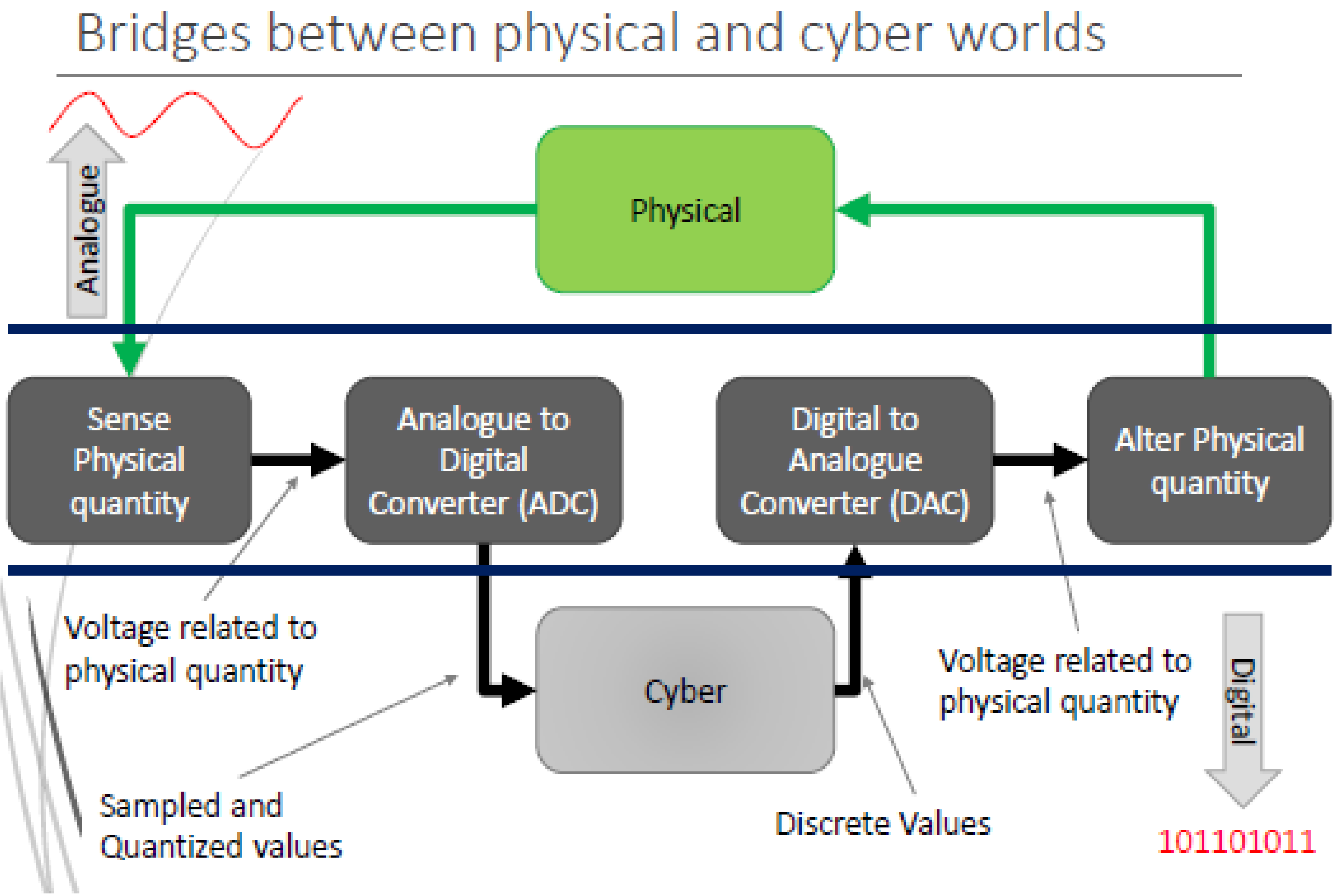
Quantifying Reality

Into a Digital World

I want to transform real variables into digital ones

Real-time, unobtrusively, in real situations, for long periods of time, with very high accuracy

Cyber-Physical Systems



(More) Pieces of the Puzzle

- Input
  - Reality (cameras, microphones, sensors, mocap, controllers,…)
  - Synthetic (computer graphics, sound synthesis,…)
- Processing
  - Digital, Analogue
  - Transform data, generate new data
- Output
  - Video, audio, actuators

Just a bit…

Sensors and Actuators – The Bridge between the Cyber and the Physical

Sensors:

- Cameras
- Accelerometers
- Rate gyros
- Strain gauges
- Microphones
- Magnetometers
- Radar/Lidar
- Chemical sensors
- Pressure sensors
- Switches
- …

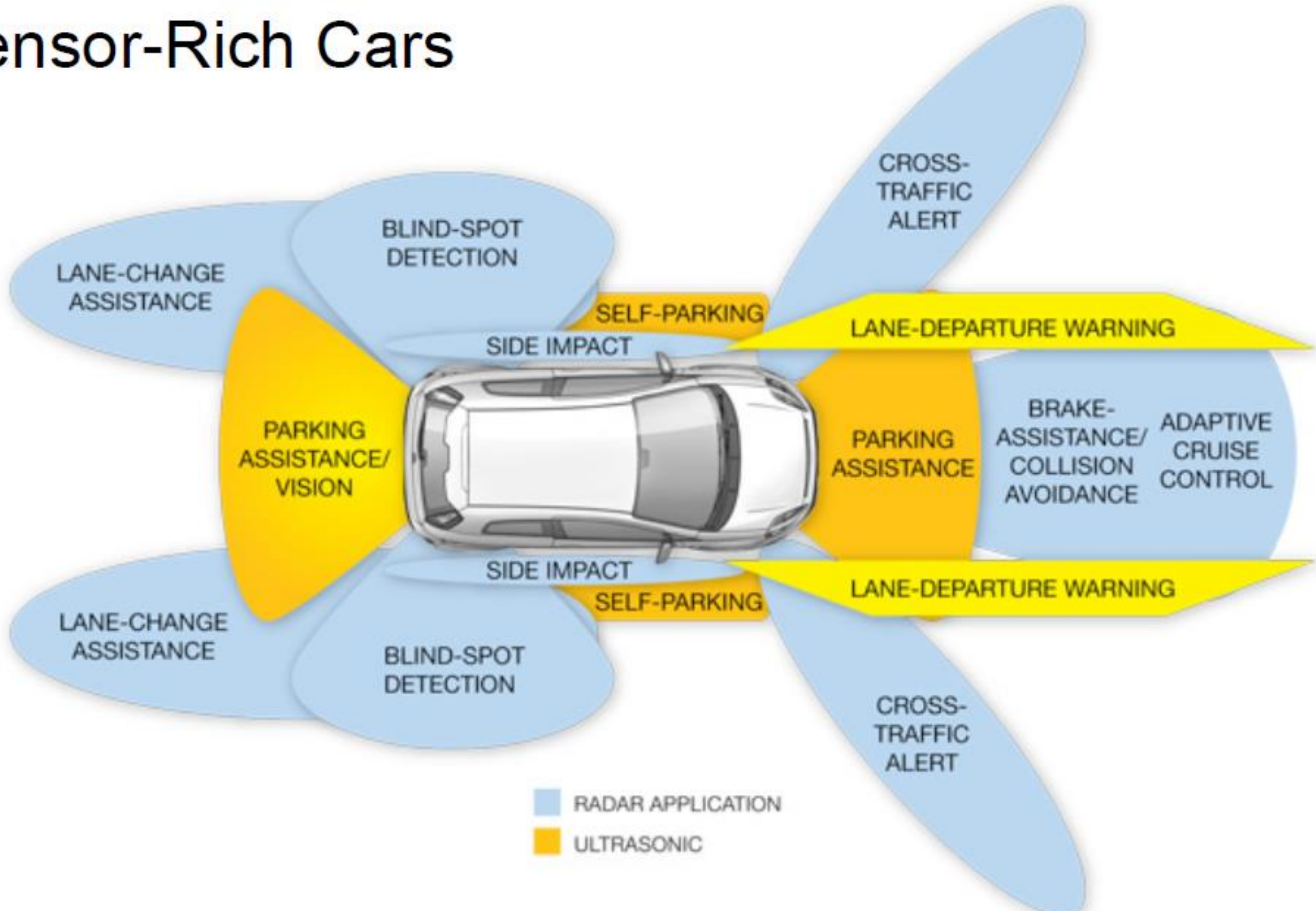
Actuators:

- Motor controllers
- Solenoids
- LEDs, lasers
- LCD and plasma displays
- Loudspeakers
- Switches
- Valves
- …

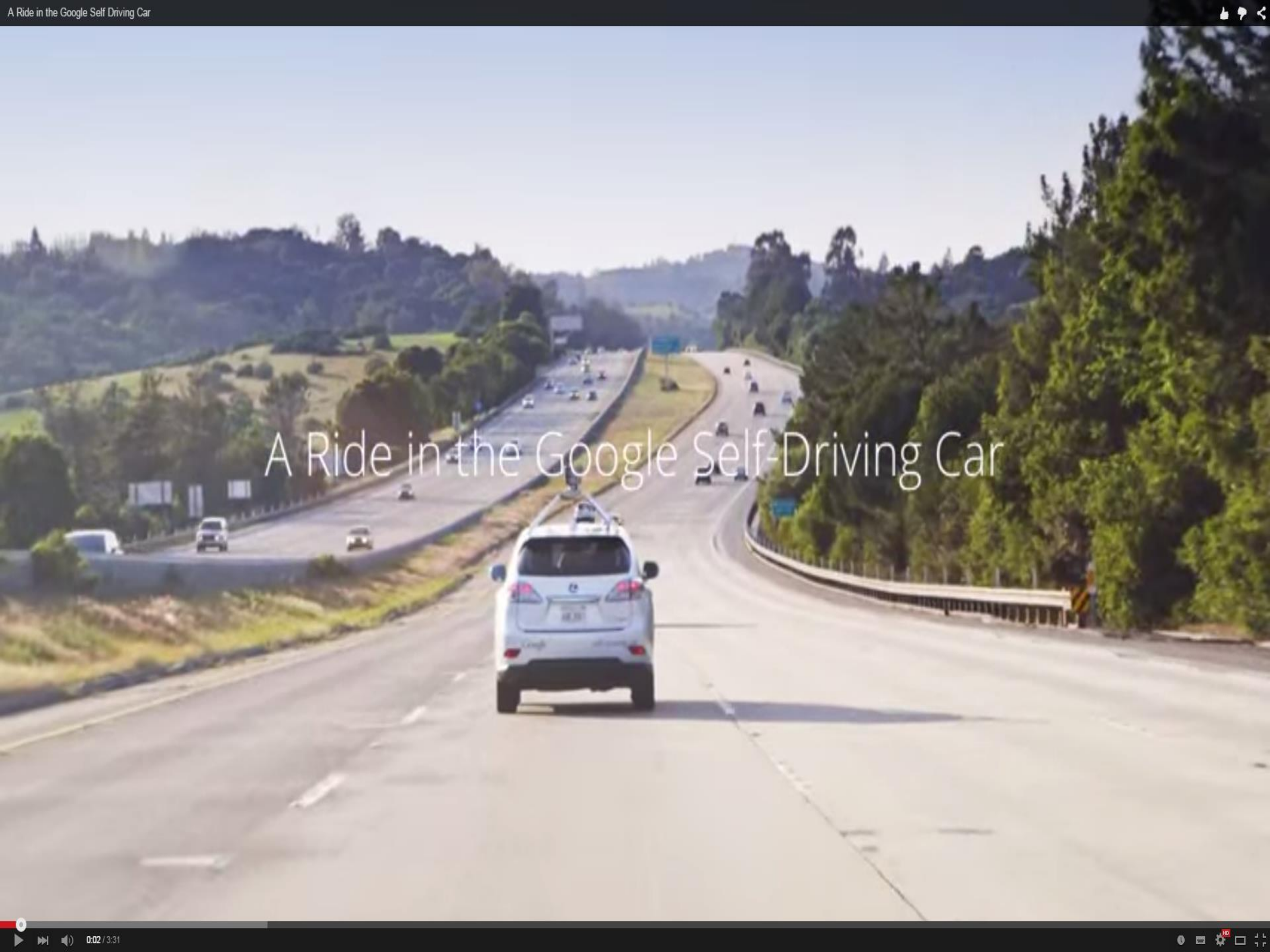
Modeling Issues:

- Physical dynamics
- Noise
- Bias
- Sampling
- Interactions

Sensor-Rich Cars



Source: Analog Devices


A Ride in the Google Self Driving Car
A Ride in the Google Self-Driving Car
0:02 / 3:31

Sensor Components

Magnetometers

A very common type is the Hall Effect magnetometer.

Charge particles (electrons, 1) flow through a conductor (2) serving as a Hall sensor. Magnets (3) induce a magnetic field (4) that causes the charged particles to accumulate on one side of the Hall sensor, inducing a measurable voltage difference from top to bottom.

The four drawings at the right illustrate electron paths under different current and magnetic field polarities.

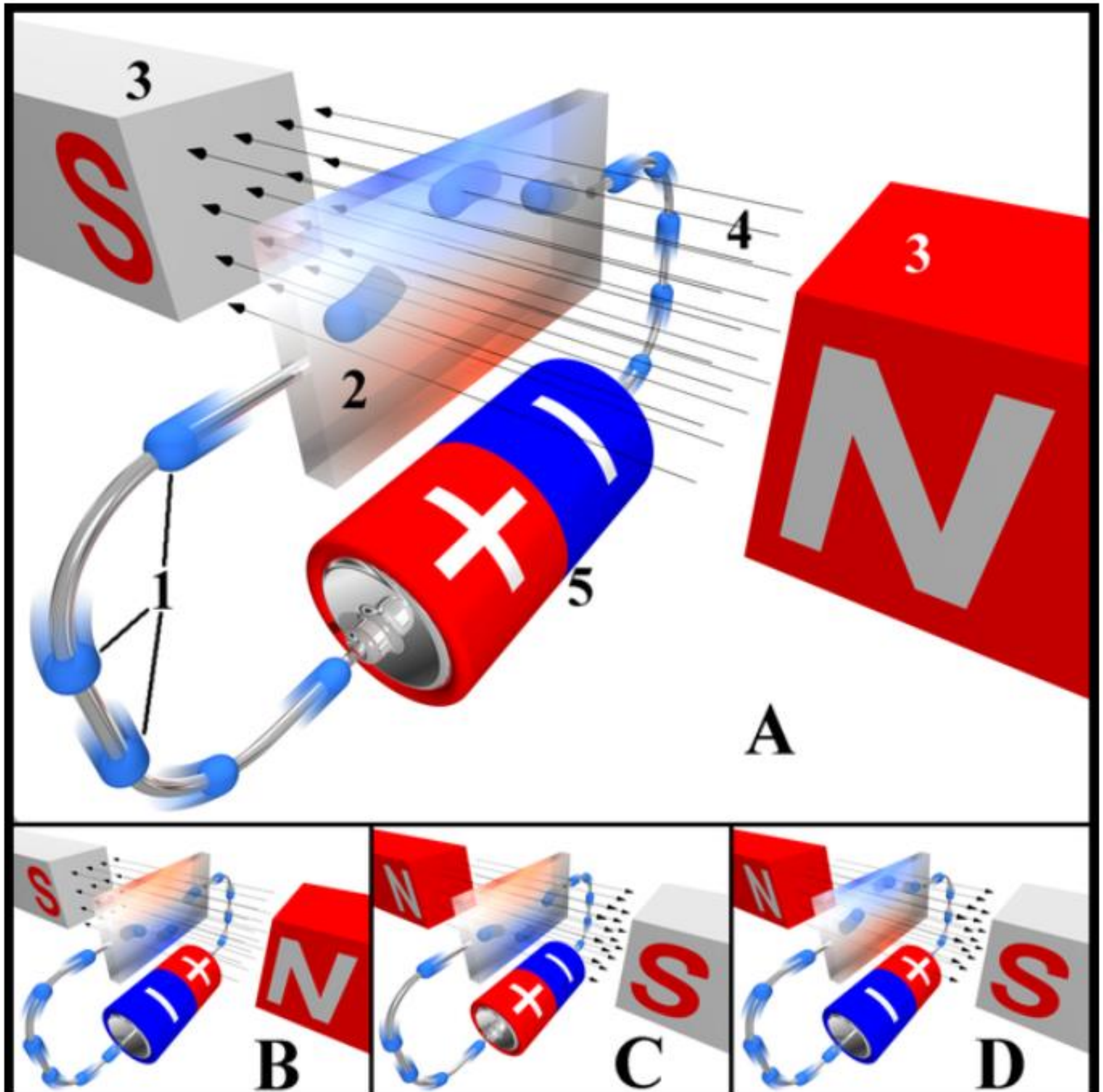


Image source: Wikipedia Commons

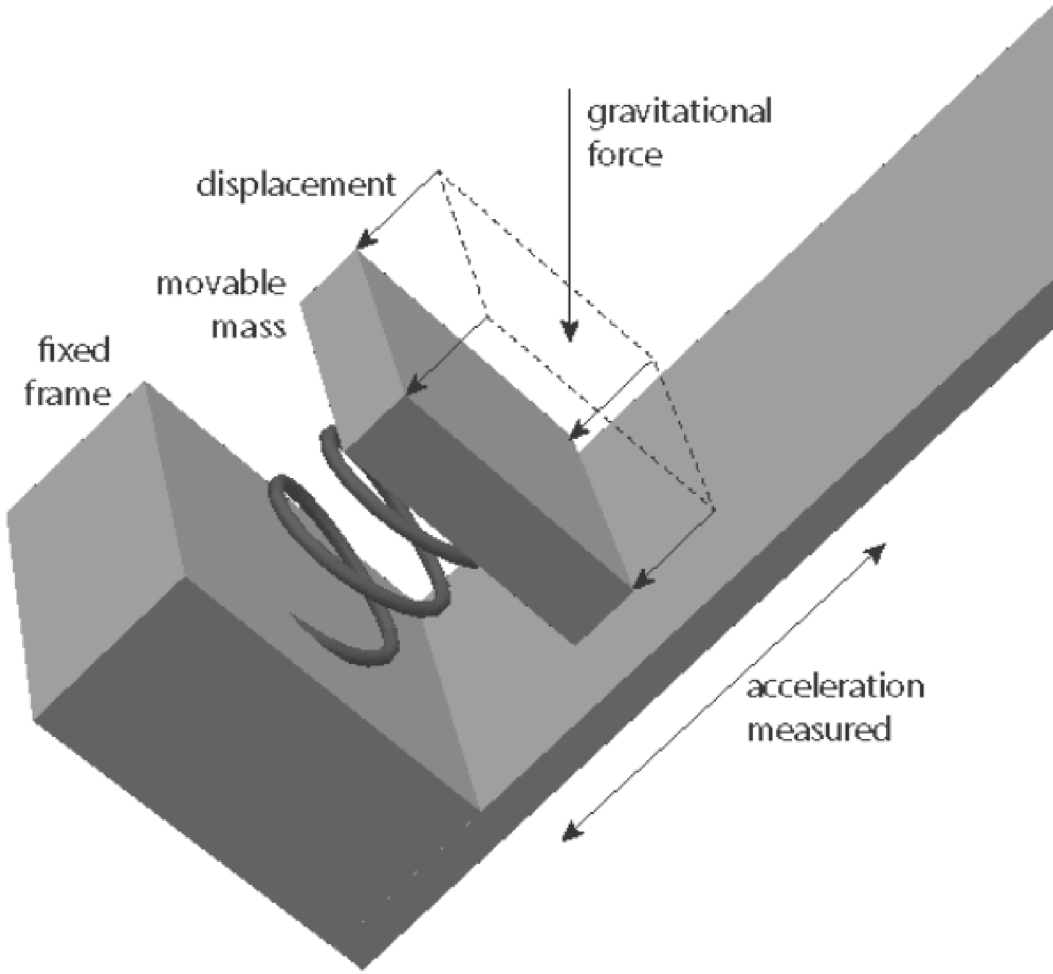
Edwin Hall discovered this effect in 1879.

Accelerometers

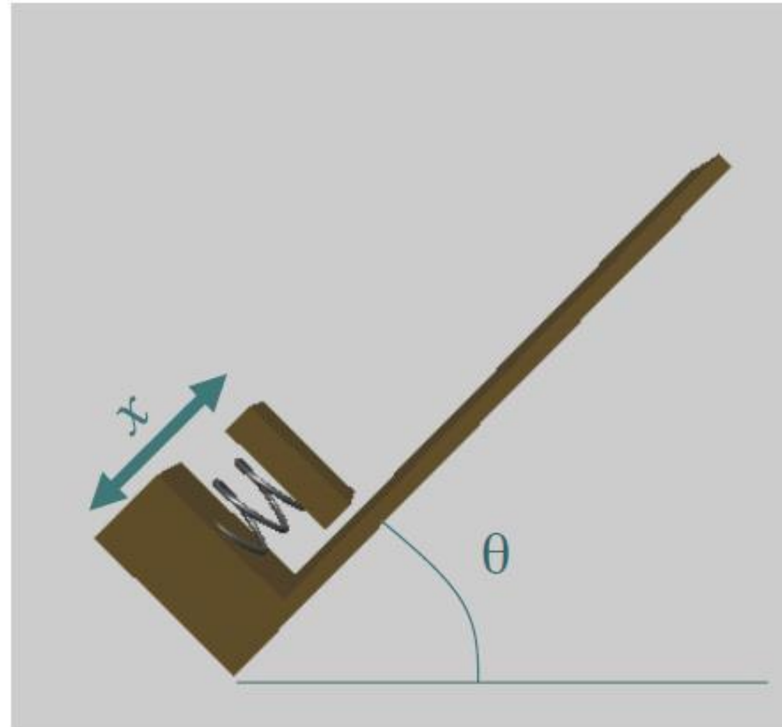
The most common design measures the distance between a plate fixed to the platform and one attached by a spring and damper. The measurement is typically done by measuring capacitance.

Uses:

- Navigation
- Orientation
- Drop detection
- Image stabilization
- Airbag systems



Measuring tilt



Component of gravitational force in the direction of the accelerometer axis must equal the spring force:

$$Mg\sin(\theta) = k(p - x(t))$$

Given a measurement of x, you can solve for θ, up to an ambiguity of π.

Difficulties Using Accelerometers

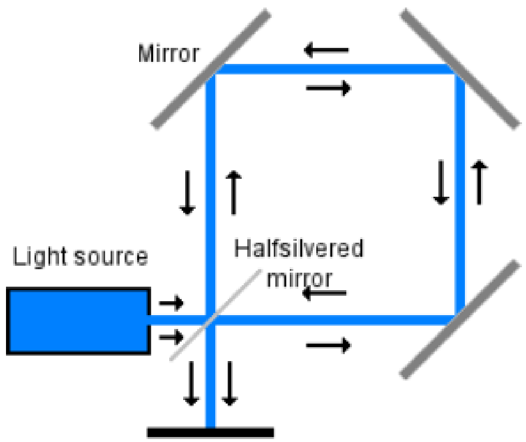
- Separating tilt from acceleration
- Vibration
- Nonlinearities in the spring or damper
- Integrating twice to get position: Drift

$$p(t) = p(0) + \int_0^t v(\tau) d\tau,$$

$$v(t) = v(0) + \int_0^t x(\tau) d\tau.$$

Position is the integral of velocity, which is the integral of acceleration. Bias in the measurement of acceleration causes position estimate error to increase quadraticly.

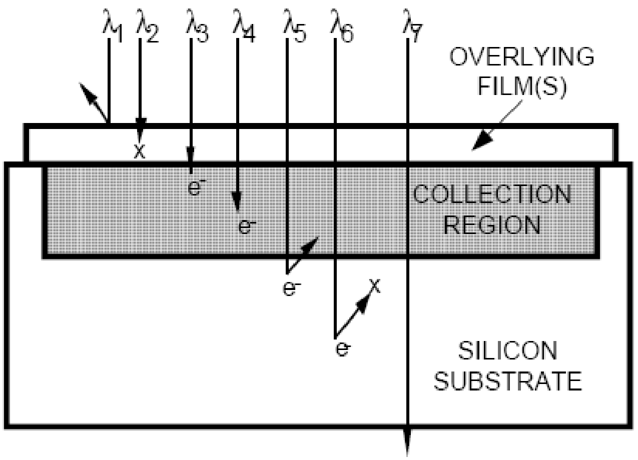
Measuring Changes in Orientation: Gyroscopes

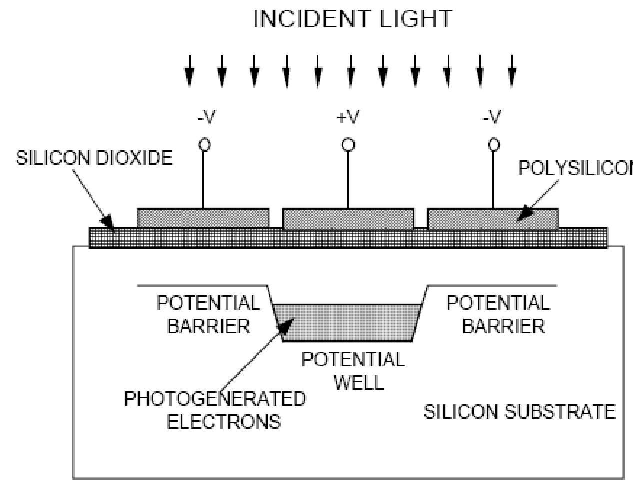


Optical gyros: Leverage the Sagnac effect, where a laser light is sent around a loop in opposite directions and the interference is measured. When the loop is rotating, the distance the light travels in one direction is smaller than the distance in the other. This shows up as a change in the interference.

Light Sensors

- Convert light into an electric charge



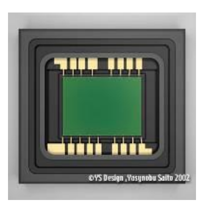


CCD (charge coupled device)

Higher dynamic range

High uniformity

Lower noise

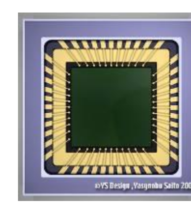


CMOS (complementary metal Oxide semiconductor)

Lower voltage

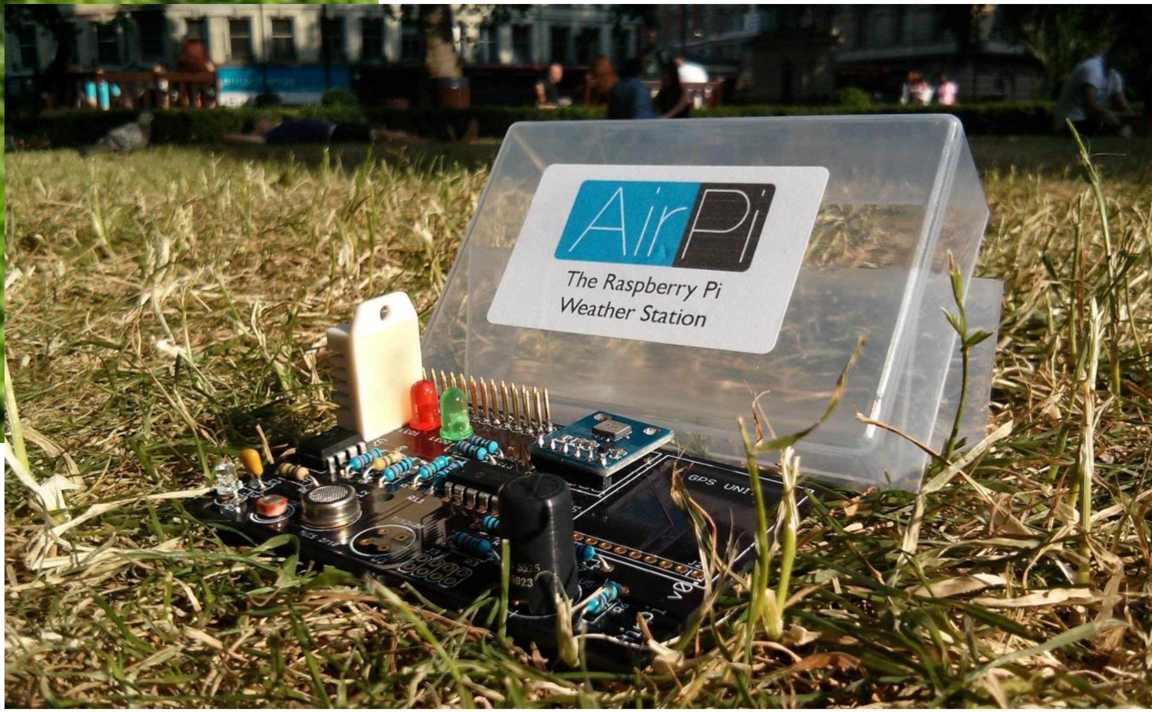
Higher speed

Lower system complexity



Environmental Sensors

- Temperature
- Humidity
- Air quality



Case Study: UrbanSense @ Porto

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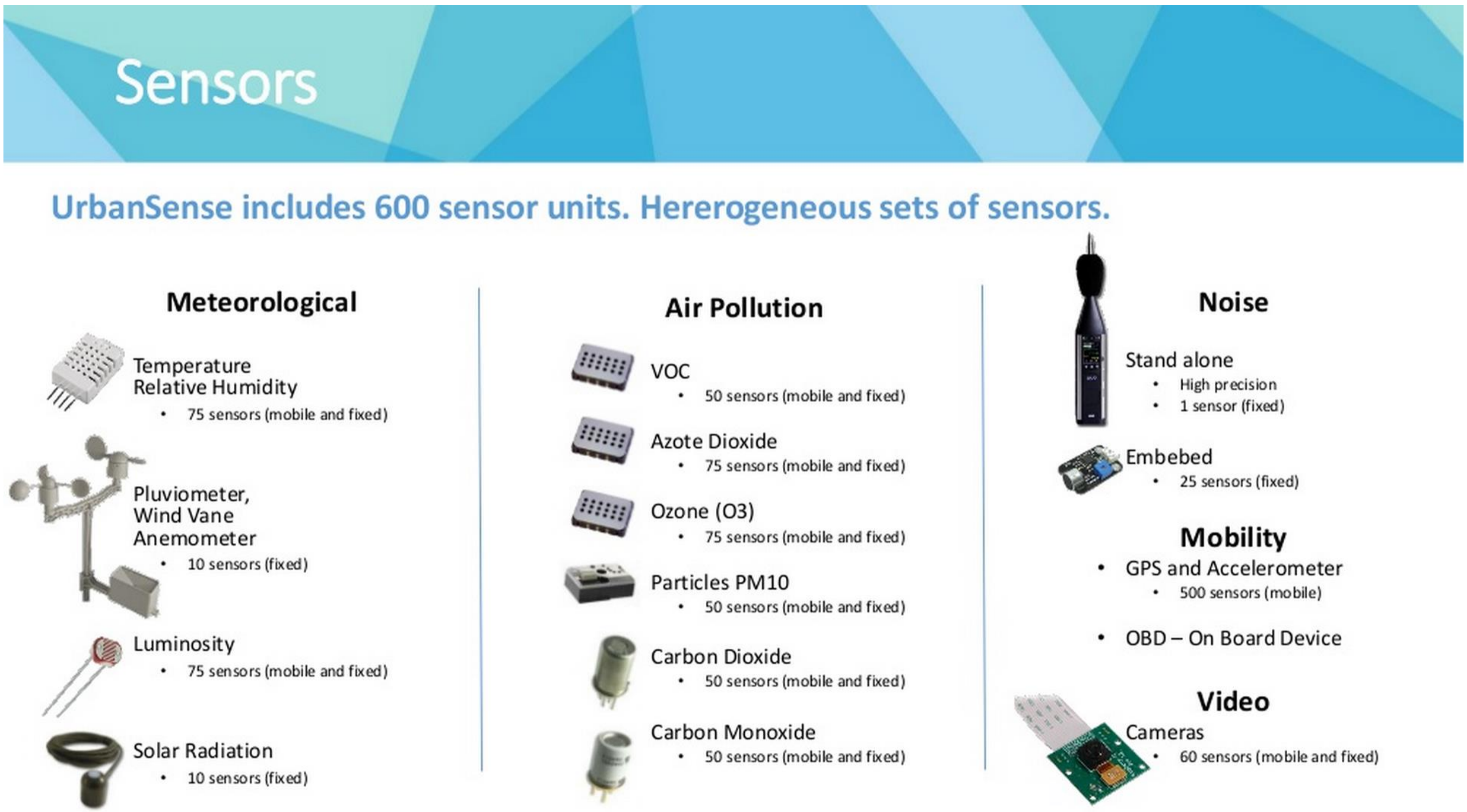
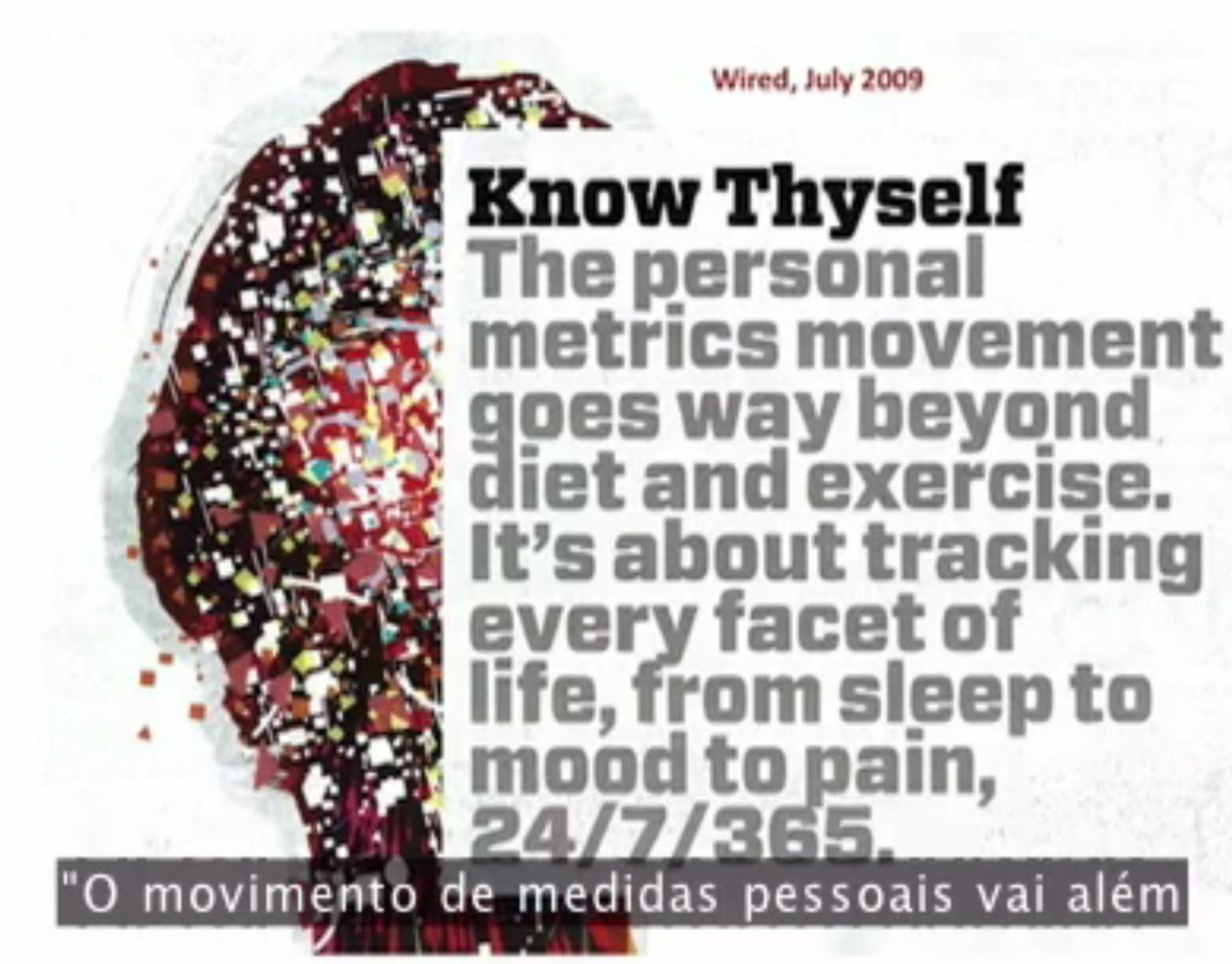


Wearable Sensors

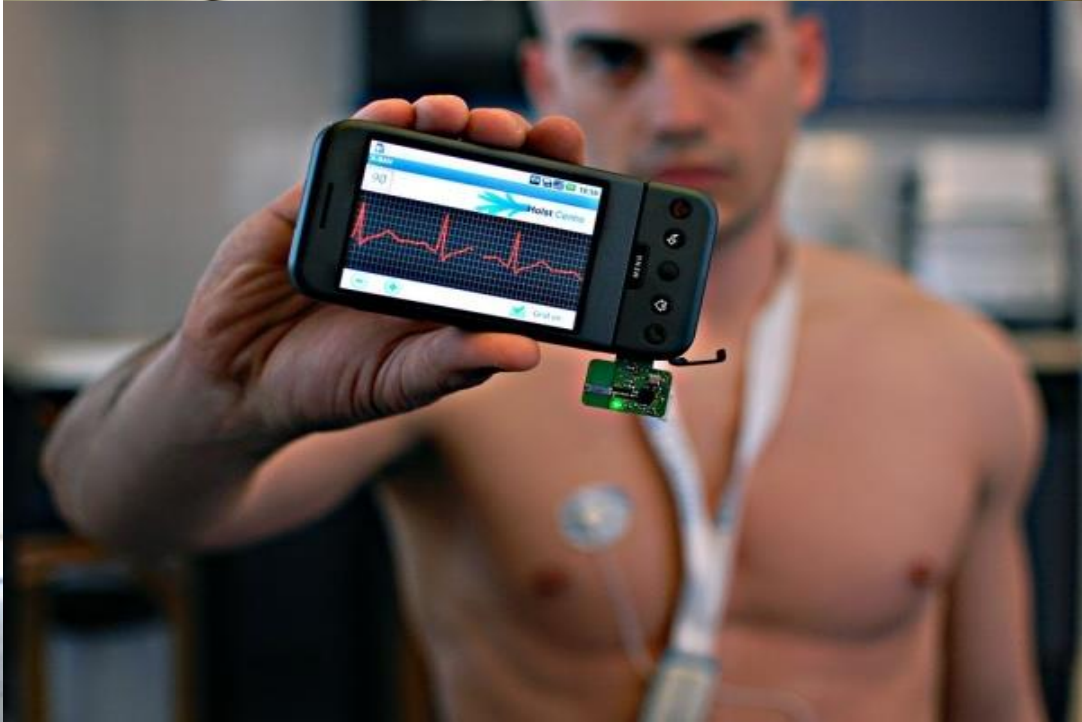
Erik Topol, 2009


Wired, July 2009

Know Thyself

The personal metrics movement goes way beyond diet and exercise. It's about tracking every facet of life, from sleep to mood to pain, 24/7/365.


HealthKiosk
HealthKiosk
HARDWARE & SOFTWARE BY: PHOENIXKIOSK.COM

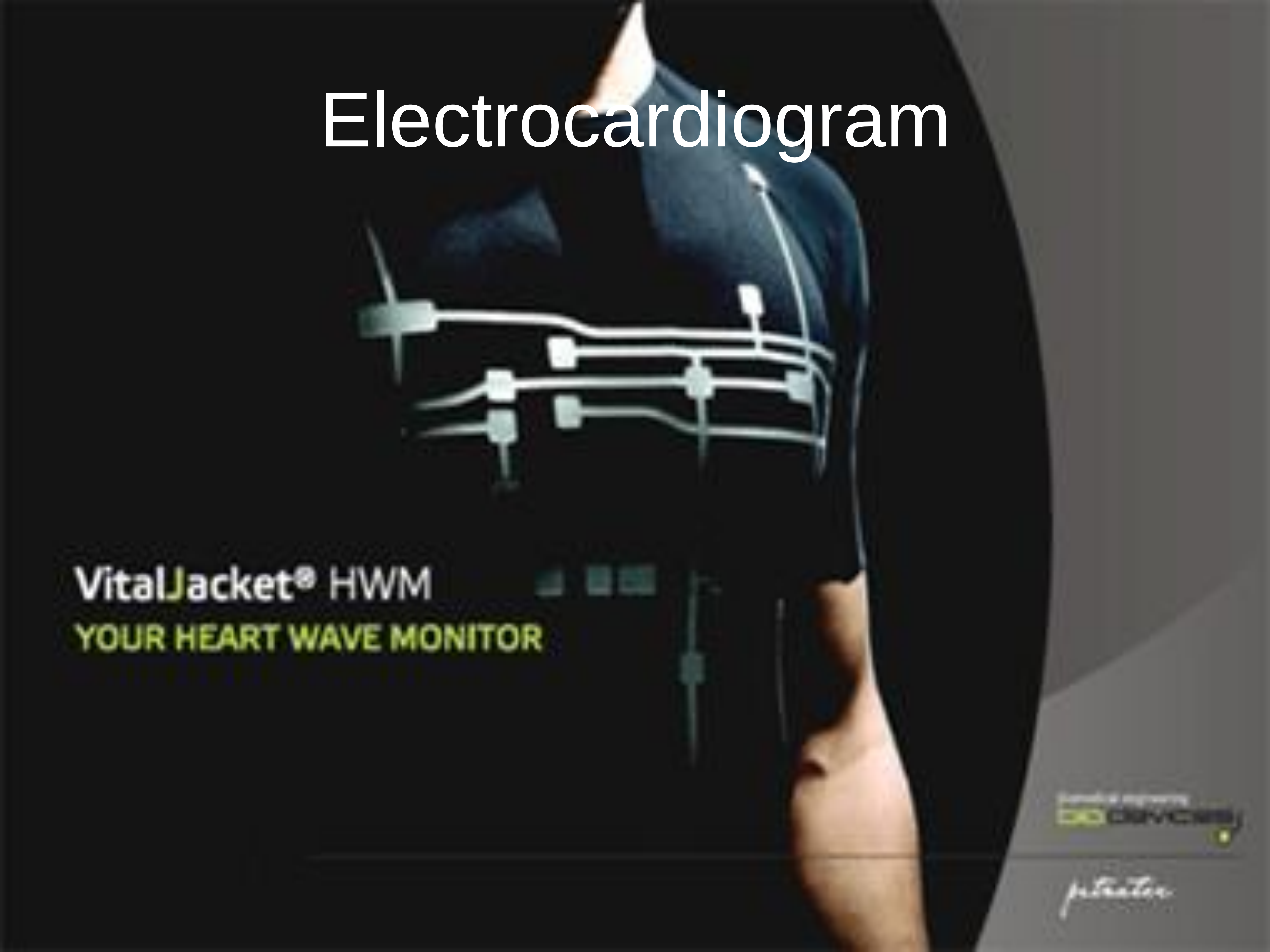

Holst Centre

Case Study: Vital Responder

Monitoring Stress Among First Responder Professionals

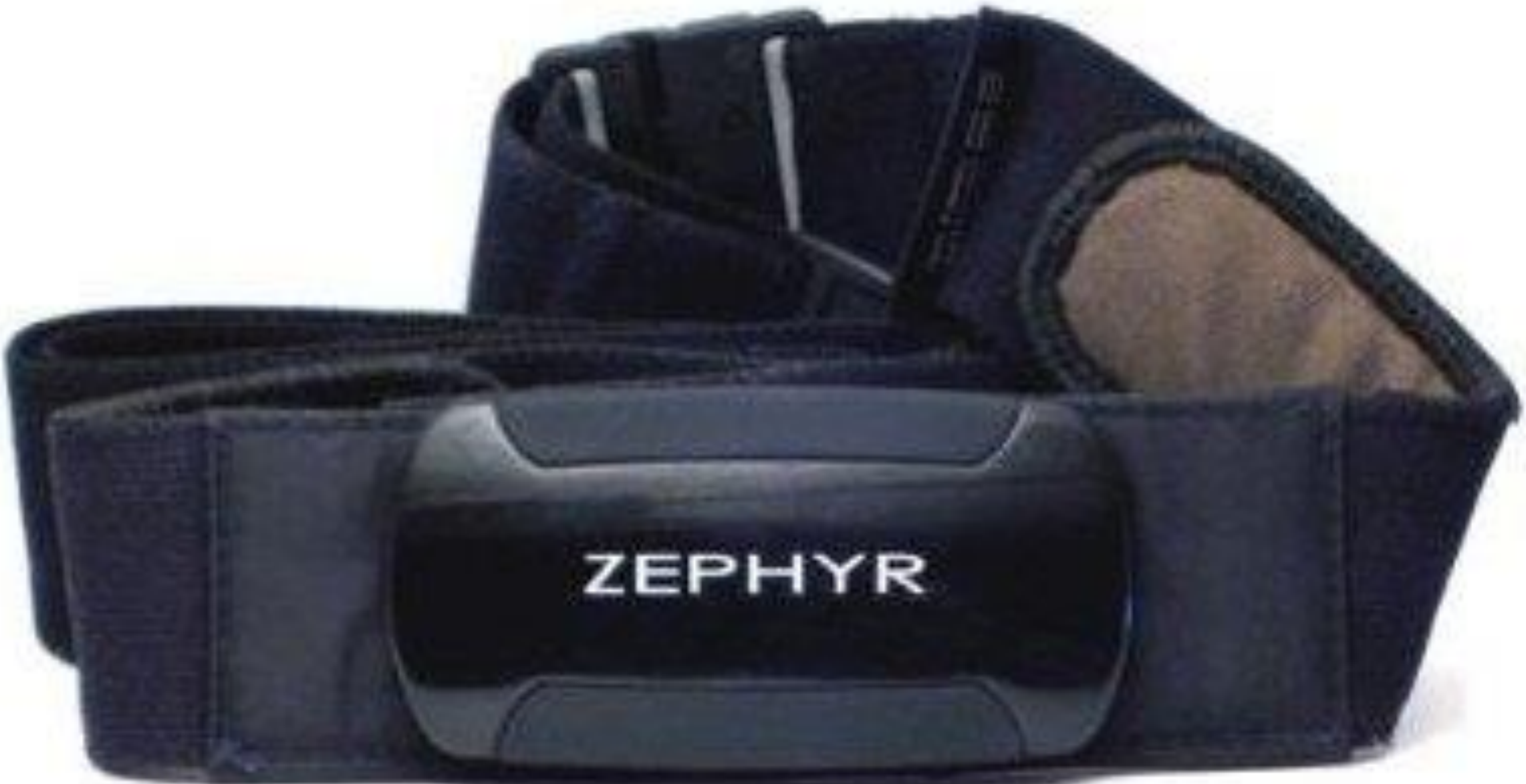

Vital Responder
00:30

Electrocardiogram



Electrocardiogram

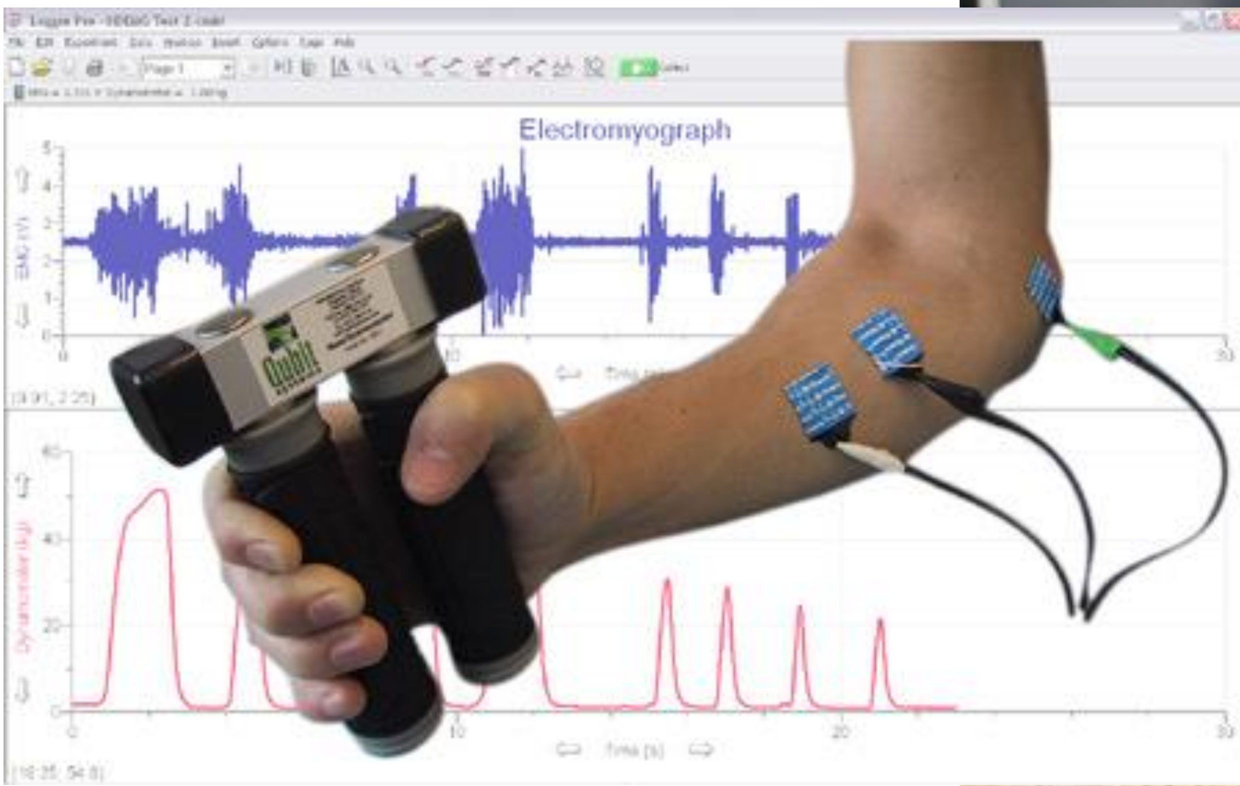
RR Variability

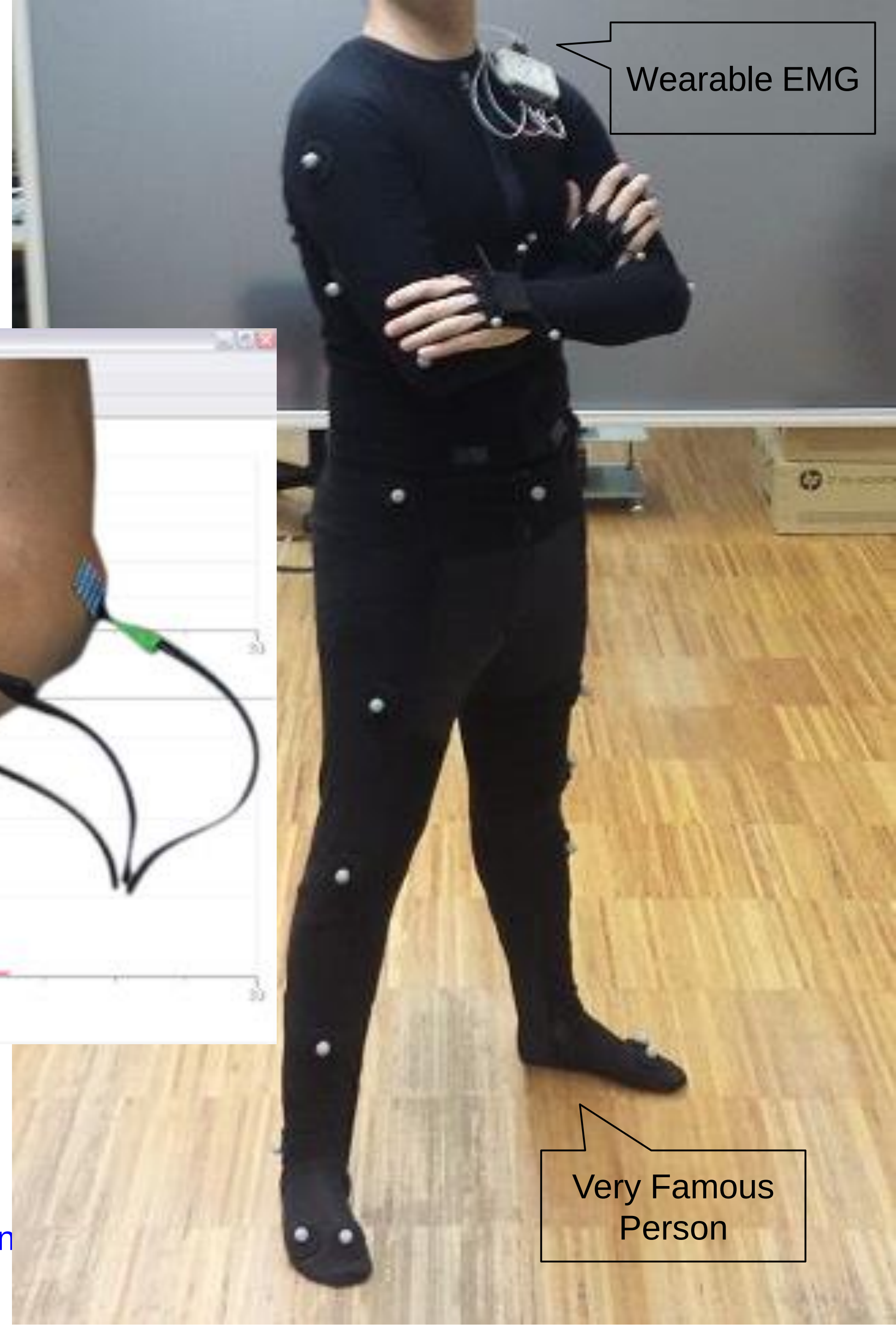


EEG

https://www.youtube.com/watch?t=55&v=T7CiiWBwMgw

EMG





Smartphone Sensing

Samsung S4

- Accelerometer
- Gyroscope
- Light
- Magnetic Field
- Atmospheric Pressure
- Proximity
- Temperature
- Humidity
- Sound Levels
- GPS

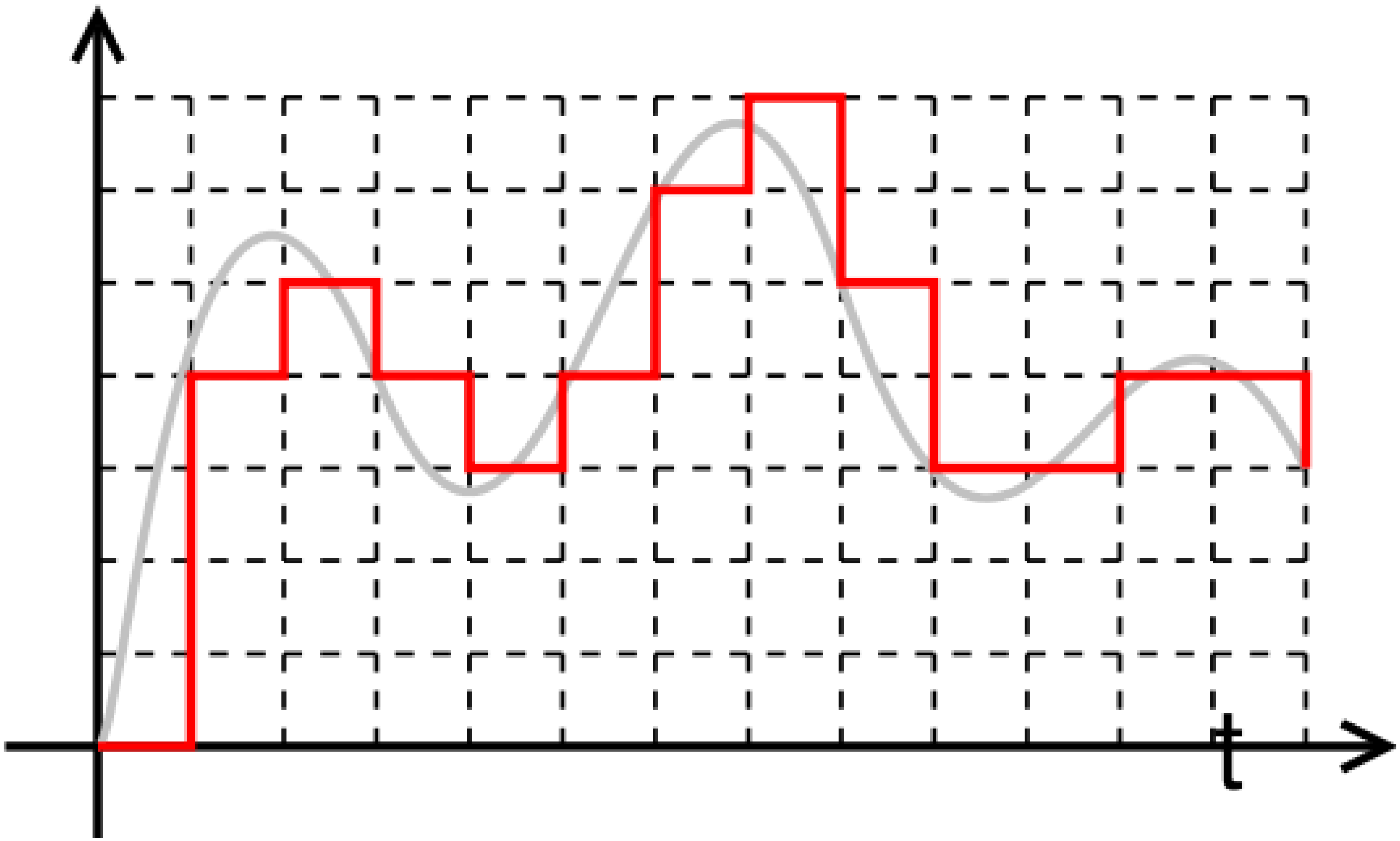
Smartwatch Sensing

Some fundamental concepts

Design Issues with Sensors

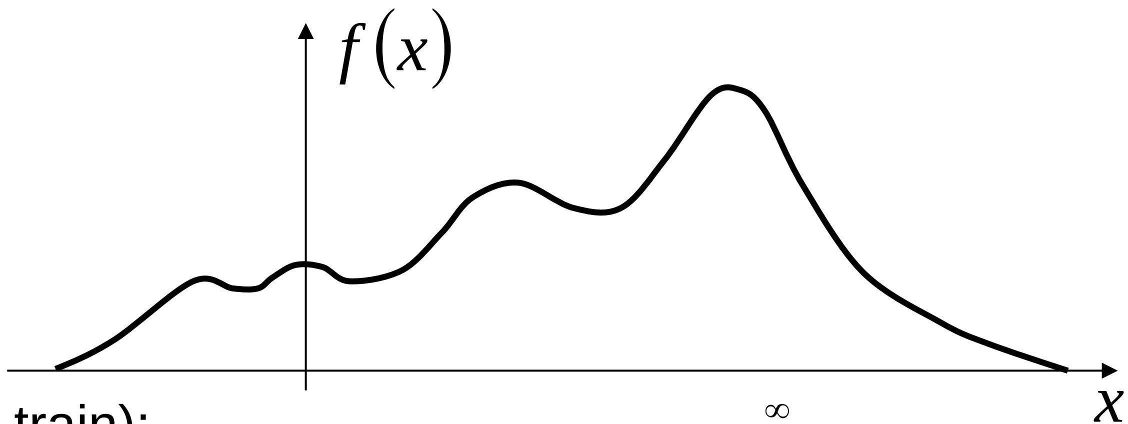
- Calibration
  - Relating measurements to the physical phenomenon
  - Can dramatically increase manufacturing costs
- Nonlinearity
  - Measurements may not be proportional to physical phenomenon
  - Correction may be required
  - Feedback can be used to keep operating point in the linear region
- Sampling
  - Aliasing
  - Missed events
- Noise
  - Analog signal conditioning
  - Digital filtering
  - Introduces latency

Analog to Digital



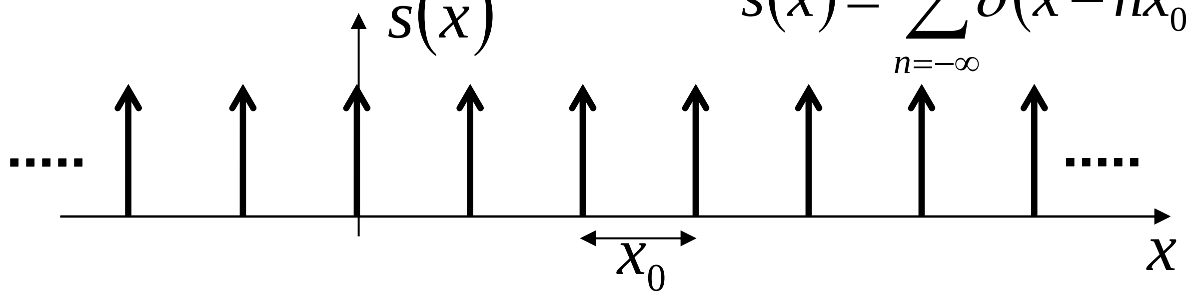
Sampling

Continuous signal:



Shah function (Impulse train):

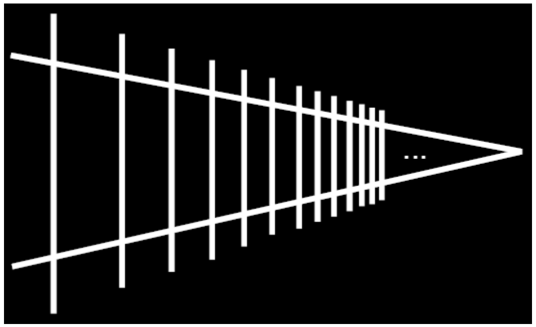
$$s(x) = \sum_{n=-\infty}^{\infty} \delta(x - nx_0)$$



Sampled function:

$$f_s(x) = f(x)s(x) = f(x)\sum_{n=-\infty}^{\infty} \delta(x - nx_0)$$

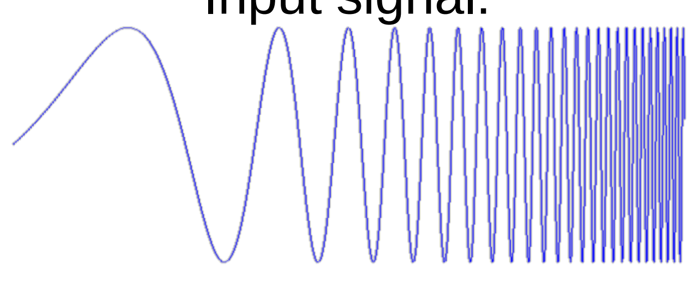
Aliasing



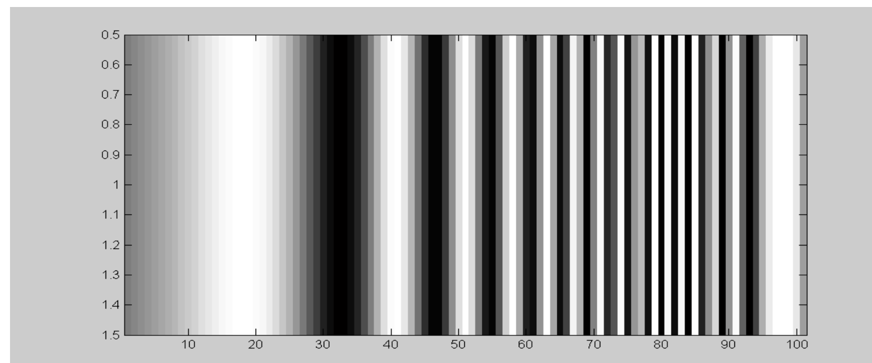
Picket fence receding into the distance will produce aliasing…

WHY?

Input signal:



Matlab output:



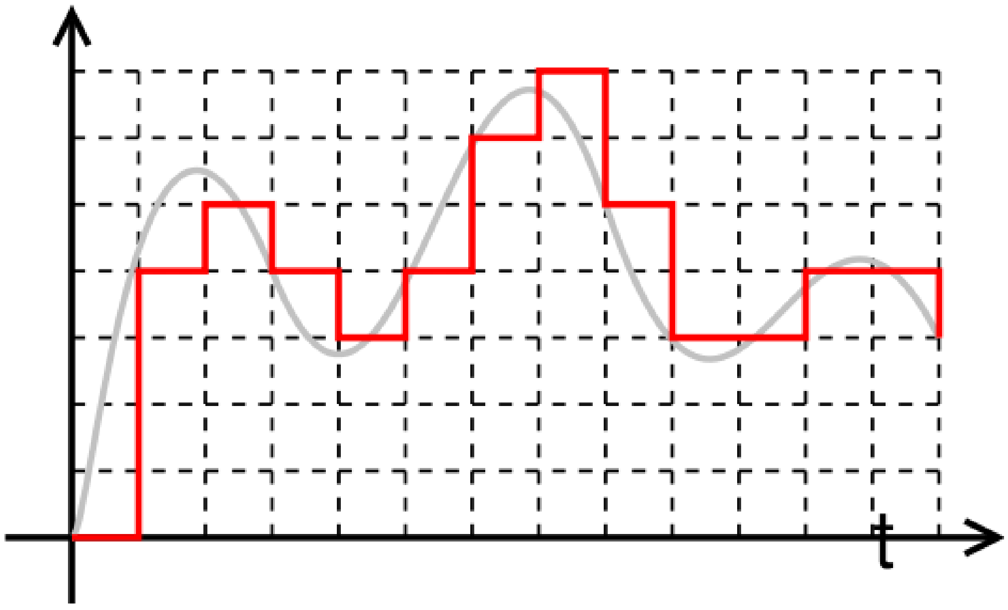
x = 0:.05:5; imagesc(sin((2.^x).*x))

Sampling frequency must be greater than $2u_{max}$

Quantization

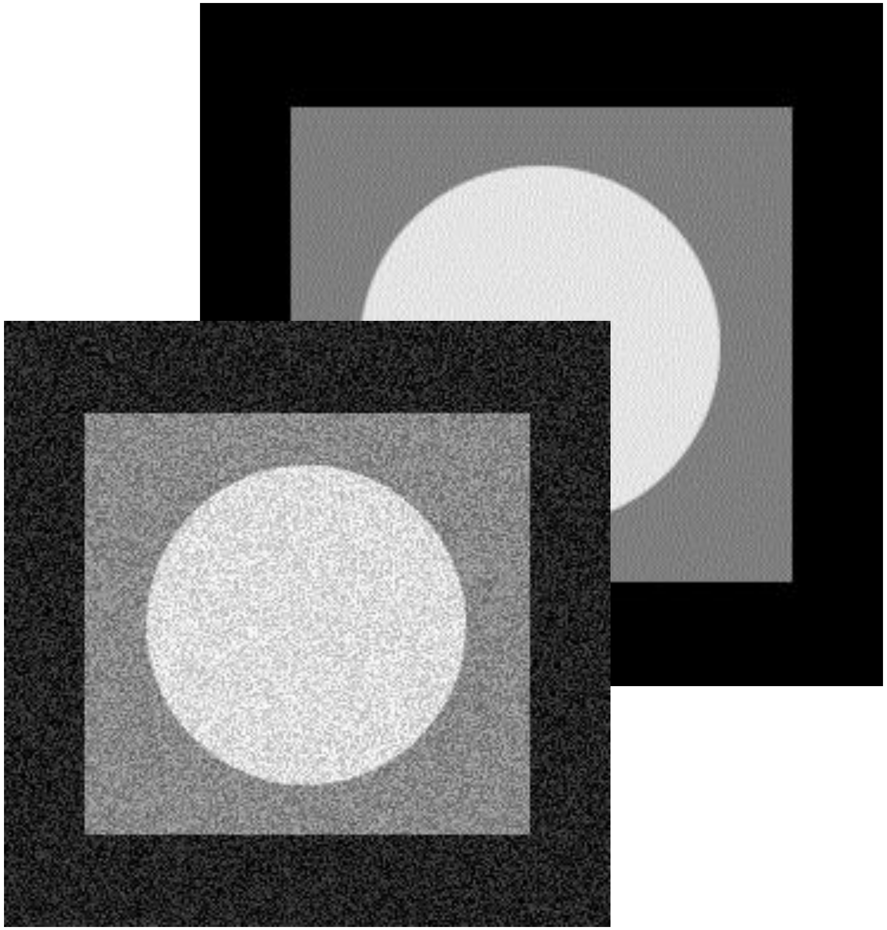
- G - number of levels
- m – storage bits
- Round each value to its nearest level

$$G = 2^m$$



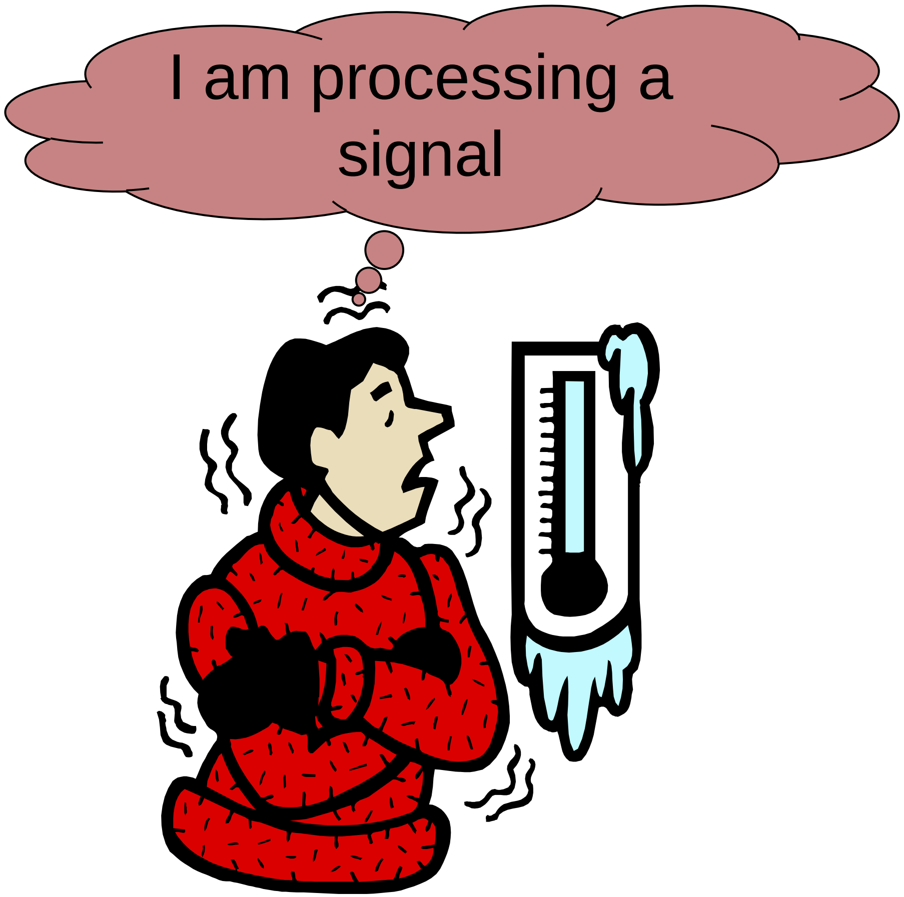
Noise

- Noise is a distortion of the measured signal
- Every physical system has noise
- Various strategies:
  - Better sensors
  - Digital Filters
  - Restoration models



Processing

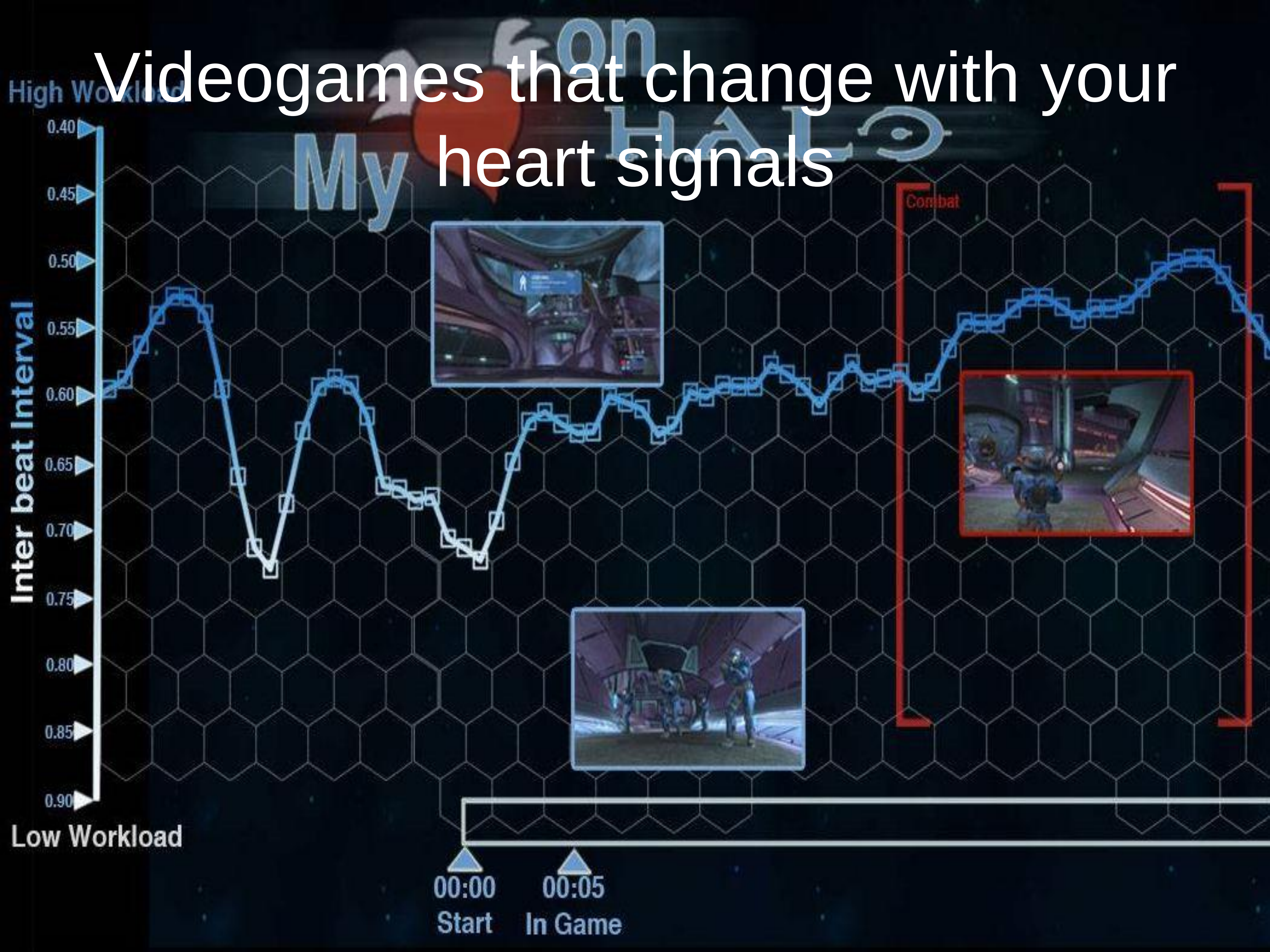
- Signal Processing
  - Analysis, interpretation, transformation of a signal
- Example
  - In order to measure temperature I ‘process’ the length of a volume of mercury



So what do I do with all this?

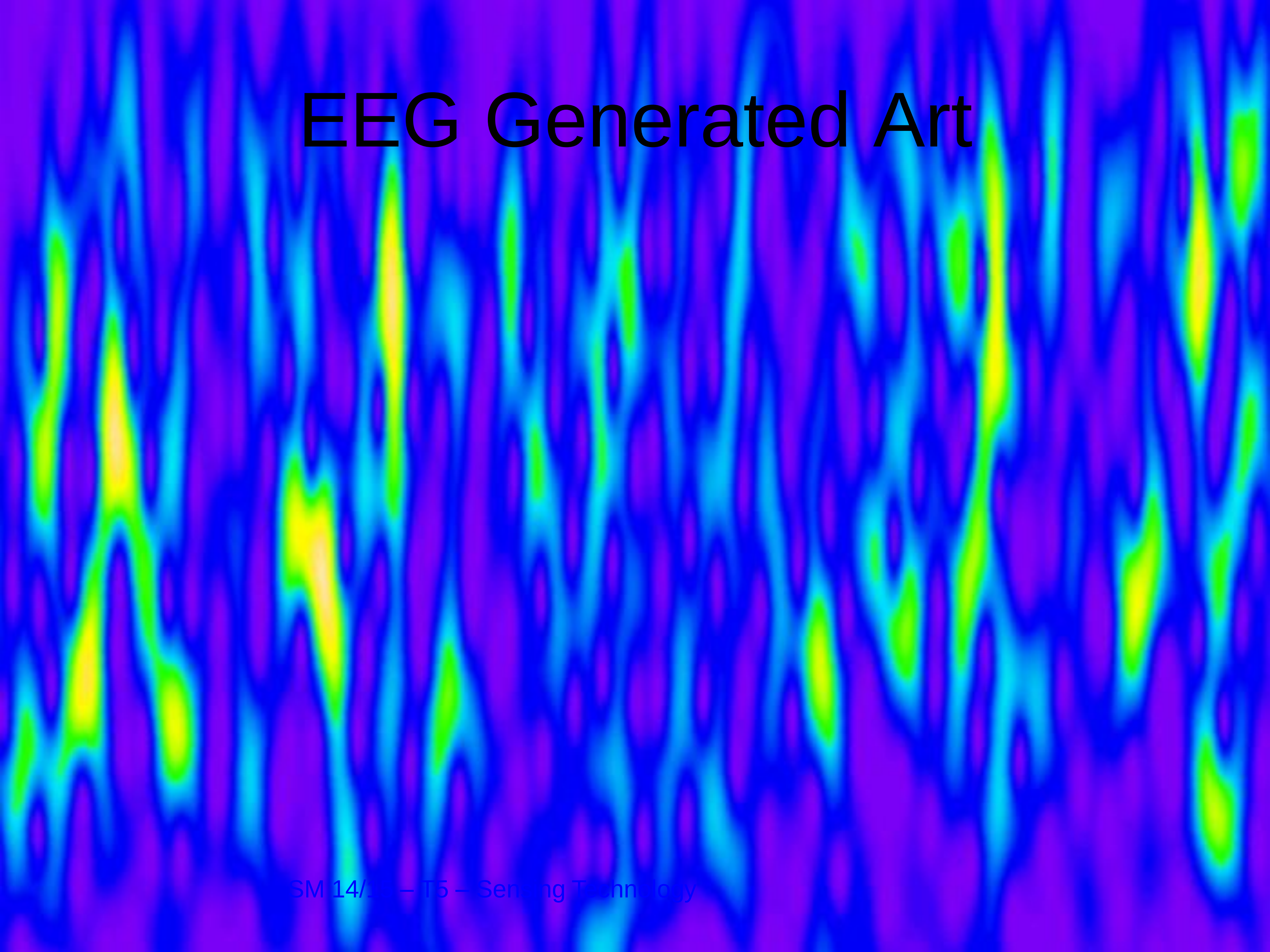
You do cool stuff of course…

Videogames that change with your heart signals



Sounds controlled by gestures

EEG Generated Art



Dating using GPS trajectories


Use CG to replay the coolest goal
from your football match
6
6

Get Creative

What will you quantify?