Smartphones and Augmented Reality for Measurement Applications

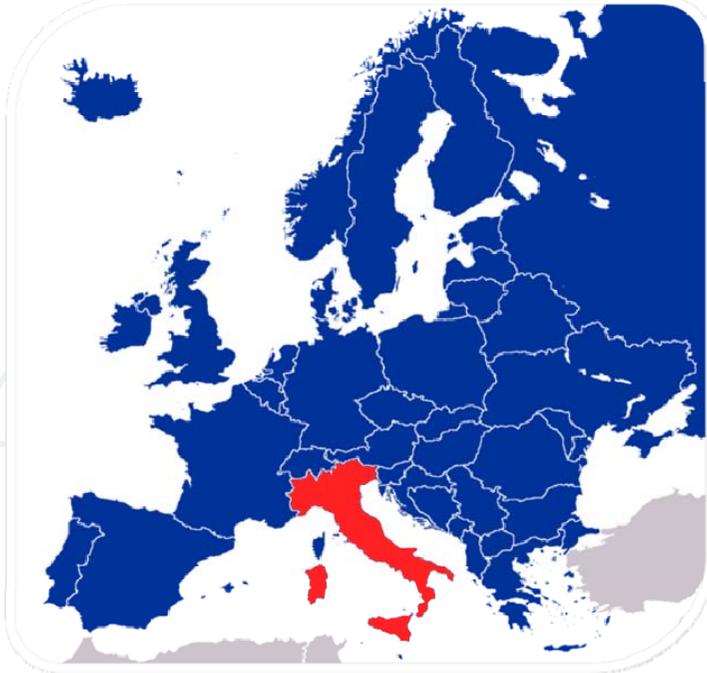Prof. Pasquale Daponte

University of Sannio

Benevento - Italy

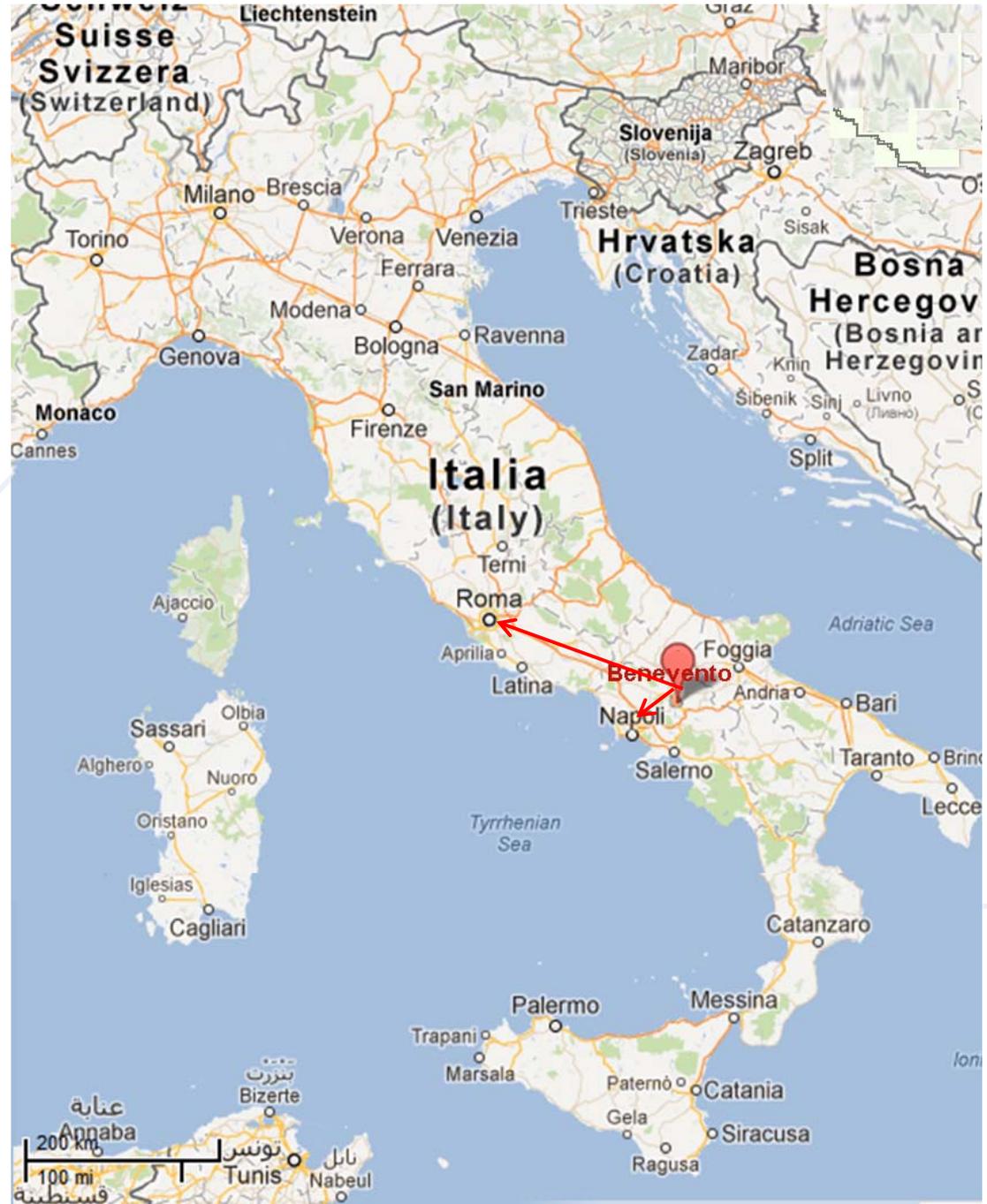**Where is Benevento ?**

Distances
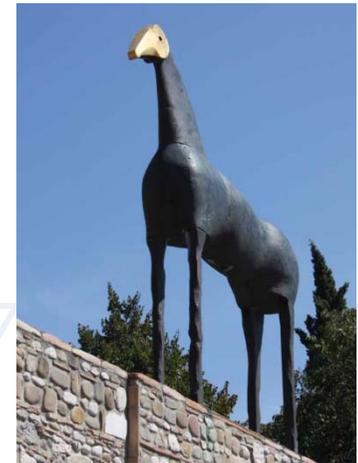**Rome** 230 km – **Naples** 80 km

The city of Benevento

Visiting Benevento is like a journey through history: the prehistoric and the Egyptian finds at the Museum of Sannio, Traiano's Arch and the Roman theatre, the Dome and the Chiesa di Santa Sofia of Longobardian times, the undergrounds of the Prefectural Palace that host ARCOS, the contemporary art museum.

University of Sannio

➢ The University of Sannio is a modern and dynamic institution in constant evolution. It is a significant part of Benevento, a small town (about 60,000 inhabitants) that offers a pleasant studying environment. With almost 8.000 students, the university gives the town a youthful spirit and a vibrant atmosphere.

➢ The University of Sannio is organized in three Departments, providing 12 BS, 12 MS and 5 Ph.D. courses.

Department of Engineering

**Dept. of Law, Economics Management and Quantitative Methods**

Department of Sciences and Technologies

Laboratory of Signal Processing and Measurement Information
L.E.S.I.M.

- LESIM is involved in:

  – Definition of new measurement methods

  – Processing of measurement information

  – Development of new electronic measurement instruments

- Application fields:

  – Distributed measurement systems

  – Characterization of electronic components - ADC and DAC Testing

  – Telecommunication - Monitoring of the radio spectrum

  – Biomedical - Monitoring of patients in rehabilitation

  – E-M-T-learning
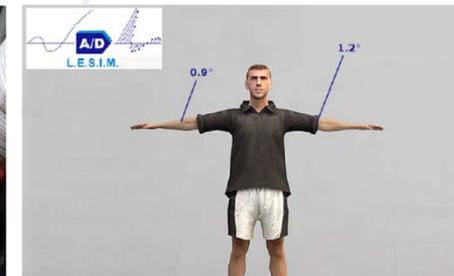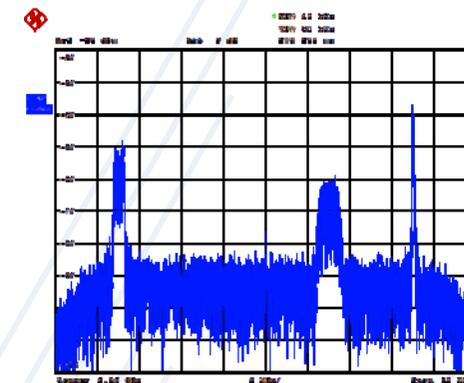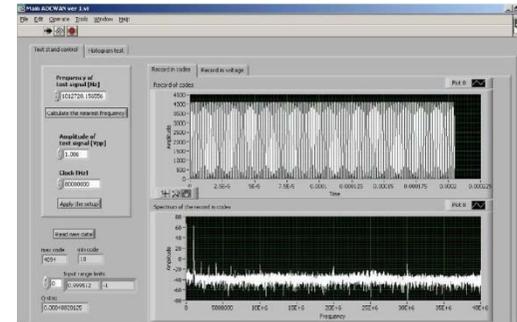
L.E.S.I.M. – Other activities

- Technical committees:
  - **IEEE** Instrumentation and Measurement Society:
    - IEEE TC-10 Waveform Generation, Measurement and Analysis Committee
    - IEEE TC-25 Medical and Biological Measurements
  - **IMEKO** TC-4 Measurement of Electrical Quantities
  - IMEKO TC-13 Measurements in Biology and Medicine
  - AdCom of IEEE Instrumentation and Measurement Society
  - SC IEC 47A Interface integrated circuits - Dynamic criteria for Analogue-Digital Converters (ADC)
  - **IEC**/TC85 Measuring equipment for electrical and electromagnetic quantities
- Standards for IEEE TC-10 :
  - IEEE Std. 1057-2007
  - IEEE Std. 1241-2010
  - IEEE Std. 1658-2011
  - IEEE Std. 181-2011
  - IEEE Std. P1696
- Standard for IEEE TC-25
  - IEEE Draft Std. P1721
- Standard for SC IEC 47
  - IEC 60748-4-3
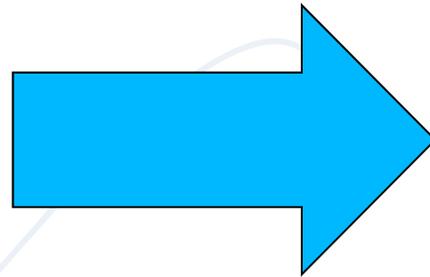- Standards for IEC TC 85/MT18
  - IEC 60469-1 and IEC 60649-2

Cooperation with C.E.R.N.

The aim of this talk is to convince you that a smartphone is a measuring instrument !!!

We need more smartphone applications, for developing measuring applications.

Outline

- ➢ Evolution of mobile phones
- ➢ Can a smartphone be considered a measurement system?
  - ✓ Smartphone Architecture
  - ✓ Smartphone Sensors
- ➢ SmartPhone based Measurement Instrument (SPMI)
  - ✓ Application fields
  - ✓ Embedded SPMI
  - ✓ SPMI Interface
- ➢ How to make smartphones even more smarter? Smartphone ever more as measurement systems
  - ✓ Measurement uncertainty
- ➢ Smartphone, Augmented reality and Measurement applications
  - ✓ Measurements for AR systems
  - ✓ The AR for measuring

A/D
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Evolution of Mobile Phones
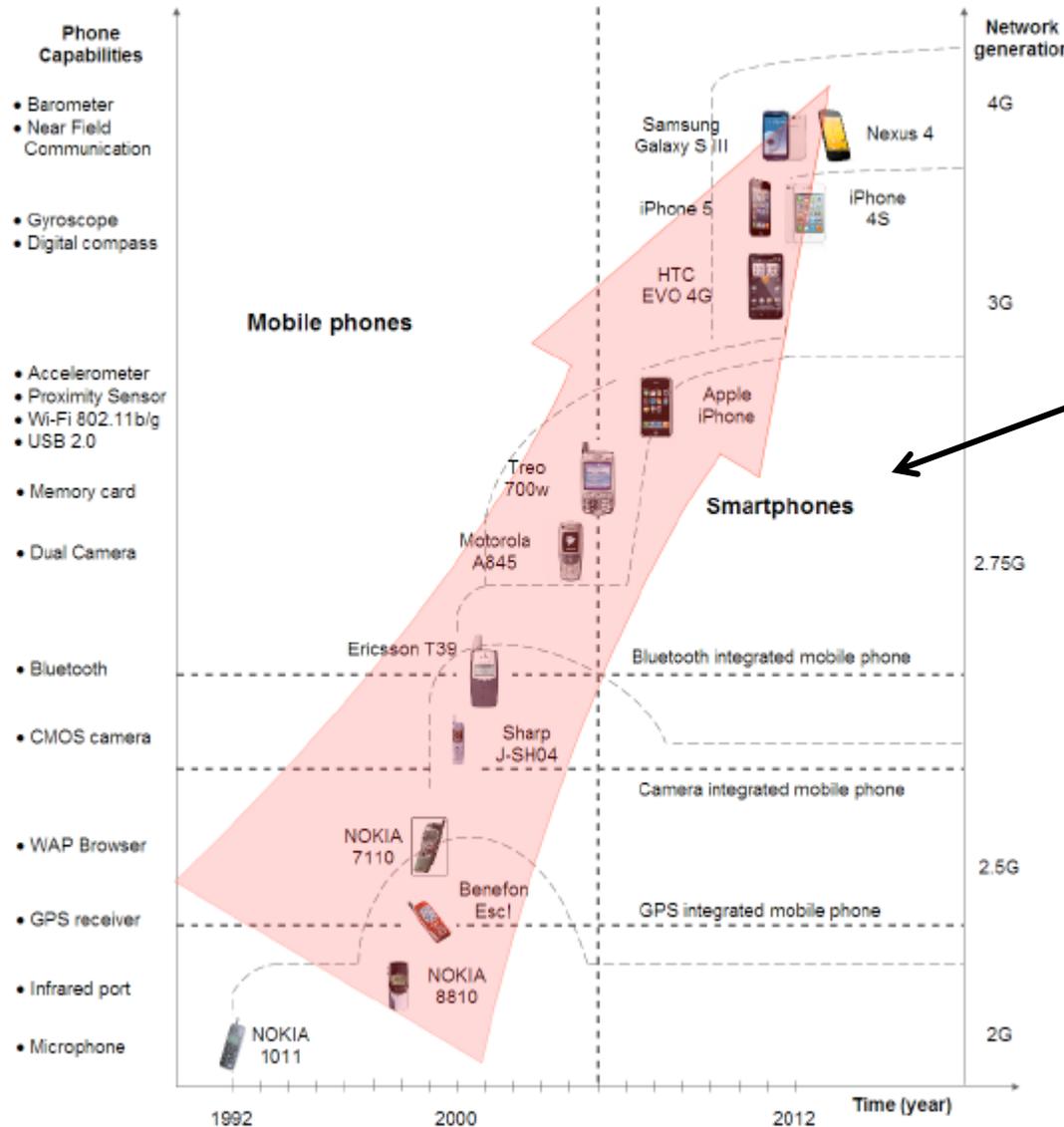
We started to use the word **smartphone** when there was the integration of **sensors** on mobile phones and the introduction of more **communication interfaces** both wireless and wired.

Market trend

➢ The smartphones are becoming even more popular and their market is expanding continuously.

  ✓ *In 2015 the 44 % of the mobile phones will be Smartphones.*

➢ Success of smartphones is leading to an increasing development of technologies, sensors and micro-electro-mechanical systems able to provide new features and services to end-users reducing cost through more integration or improvements in hardware performances.

➢ The definition of smartphone has changed in the time. **The simplest mobile device on the market today, has been considered a smartphone some years ago.**

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Smartphone

➢ Nowadays, a smartphone has a multitasking operating system, a full desktop browser, Wi-Fi capability, 3G connection, a music player, a GPS or an Assisted GPS, a digital compass, video camera, TV out, Bluetooth, touch display, 3D video acceleration and Inertial Magnetic Sensors (IMS).

Someone defines the smartphone like a pc linked to sensors.

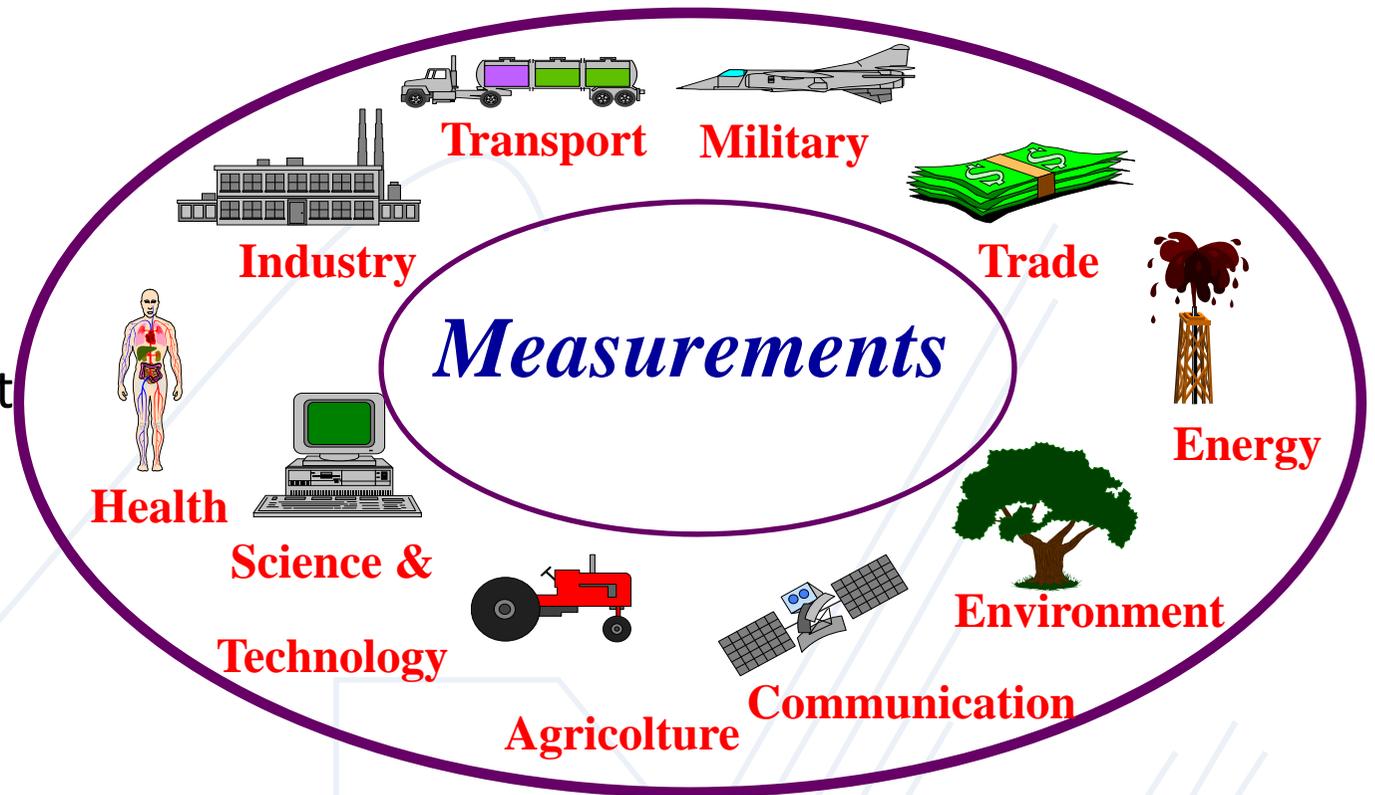# Can a smartphone be considered a measurement system?

Smartphone as a Measurement System

In the everyday experience, it is necessary to make measurements.

Anytime we interact with the environment around, we make measurements of physical quantities.

For this reason, it is important that measurements are available as friendly as possible for specialized and non-specialized people.

Measurements

Transport Military

Industry Trade

Health Energy

Science & Technology Environment

Agricolture Communication

For the everyday experience, a usable measurement system has the following features:
- non-invasive
- user friendly
- portable.

Smartphone as a Measurement System

➢ A modern **smartphone allows measuring** of different physical quantities directly from its embedded sensors, e.g. three-axis accelerometer, three-axis magnetometer, barometer, light sensor, and so on.

➢ Moreover, the **smartphone can communicate** with other apparatus (e.g. wireless sensor nodes, data acquisition boards etc.) through wireless interfaces, such as Bluetooth, Wi-Fi and Near Field Communication (NFC).
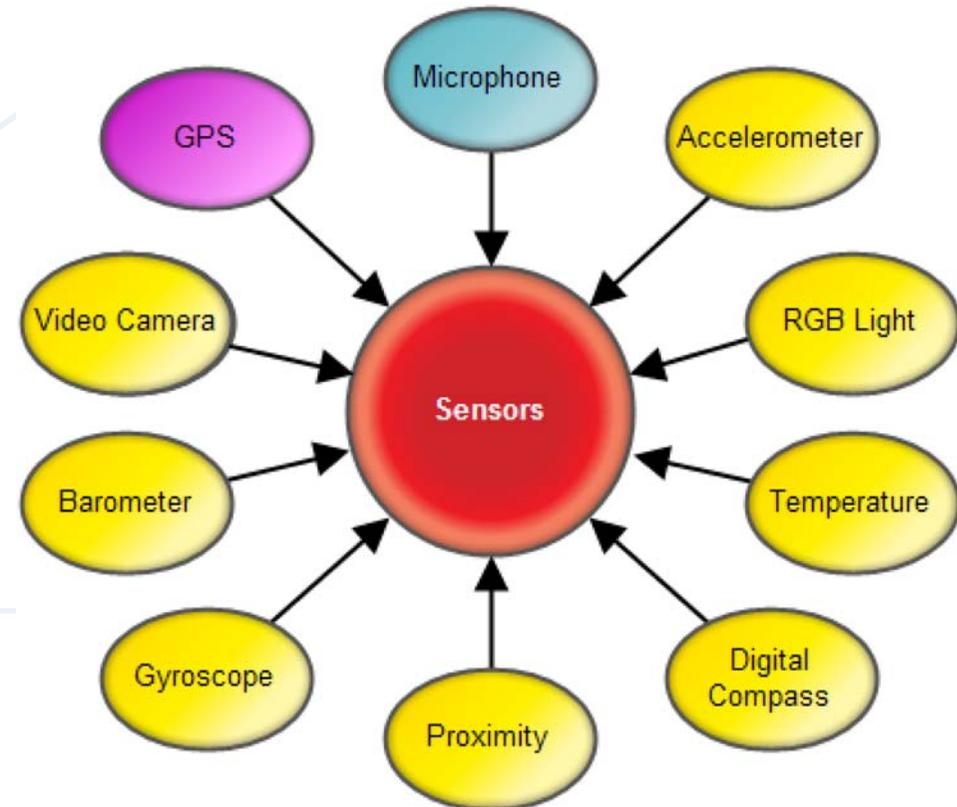
Thanks to these technologies, the smartphone is candidate to be considered as a measurement system.

GPS · Microphone · Accelerometer · Video Camera · Sensors · RGB Light · Barometer · Temperature · Gyroscope · Proximity · Digital Compass

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General architecture of a smartphone

- ➤ Application Processor (AP)
- ➤ GPS module
- ➤ Network interface
- ➤ Data transfer interface
- ➤ Sensors
- ➤ Power Management (PM)
- ➤ External Memory
- ➤ Subscriber Identity Module (SIM)
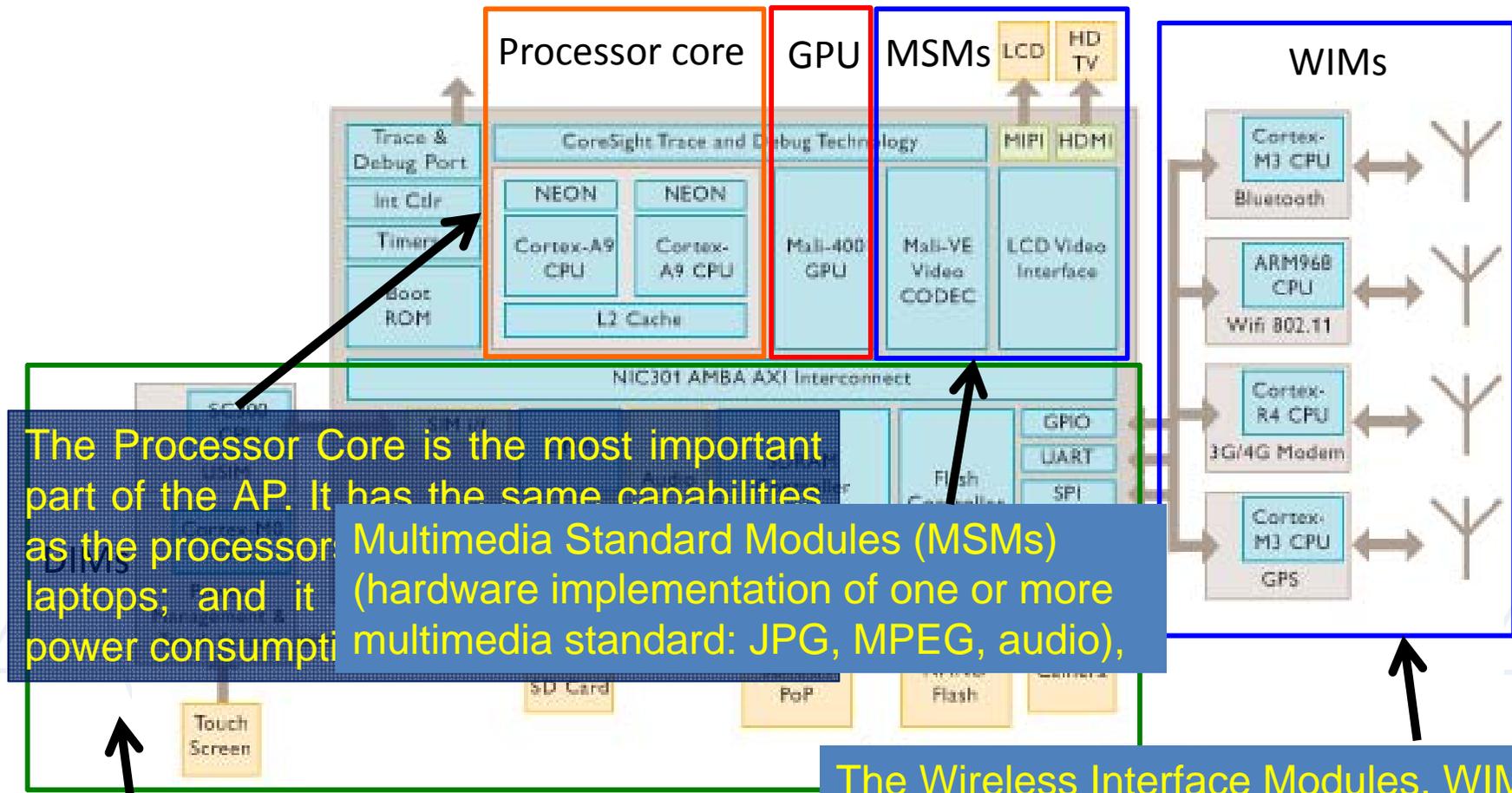- ➤ Touch display
- ➤ Internal Memory
- ➤ Speaker module
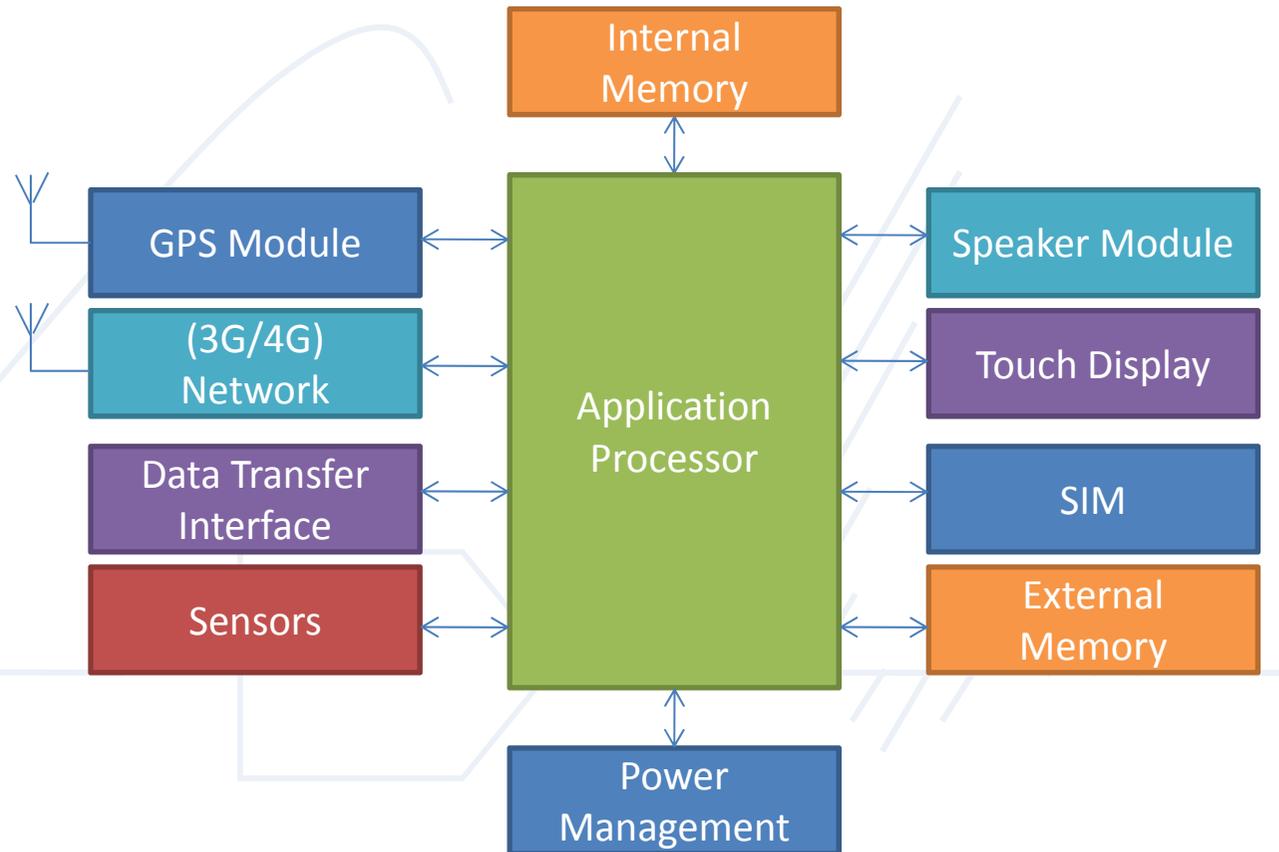
Application Processor (AP) is a System-on-Chip (SoC) which contains different multimedia components

# Application Processor (AP) is a System-on-Chip (SoC) which contains different multimedia components
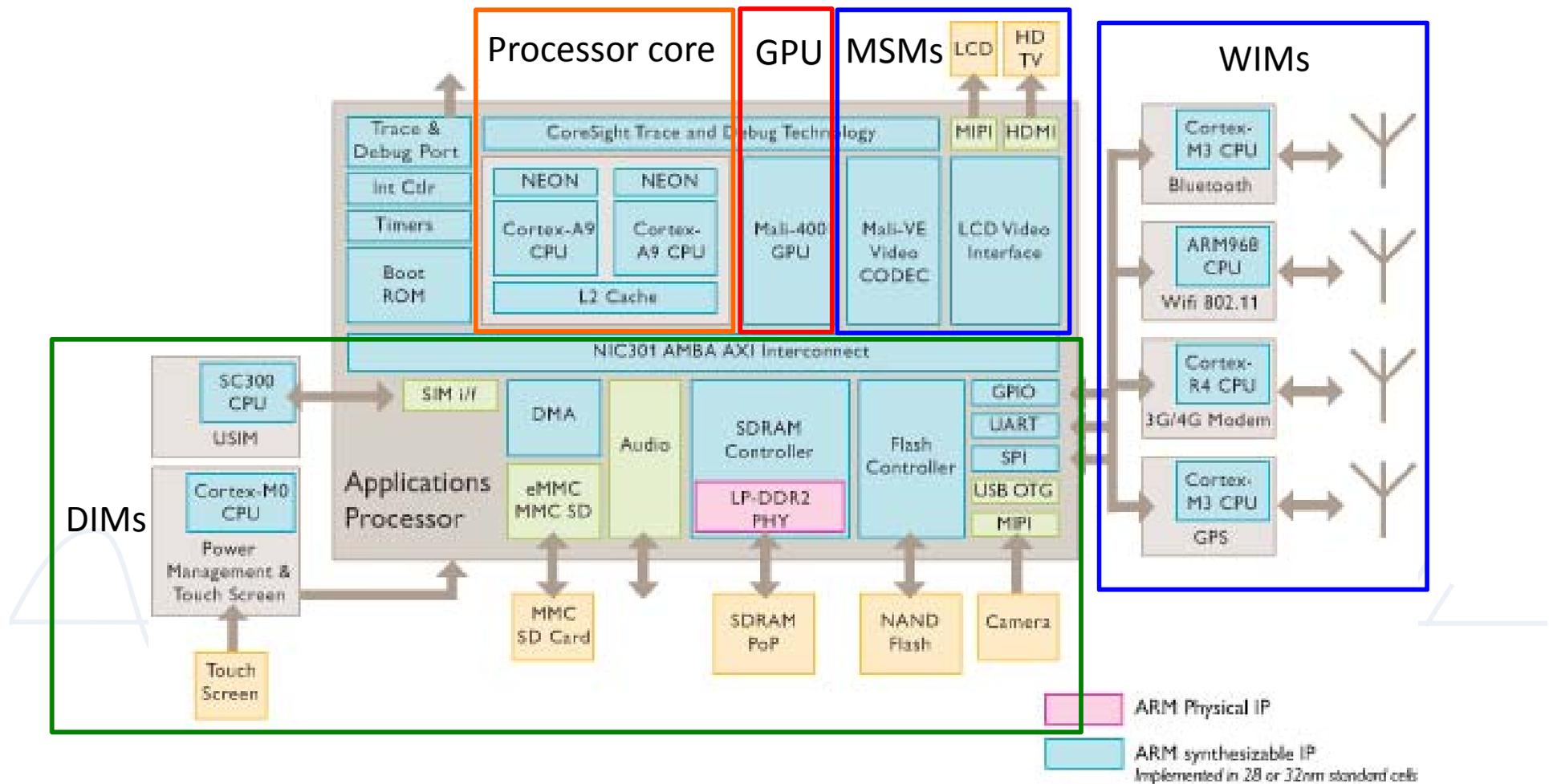
Processor core | **GPU** | **MSMs** | **WIMs**

The Processor Core is the most important part of the AP. It has the same capabilities as the processors laptops; and it power consumpti

Multimedia Standard Modules (MSMs) (hardware implementation of one or more multimedia standard: JPG, MPEG, audio),

The Wireless Interface Modules, WIMs, are used for the wireless communication, for example Bluetooth, GSM and Wi-Fi.

Device Interface Modules (DIMs) (for the communication with peripheral devices: touch display, video camera).

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Smartphone Sensors (1)
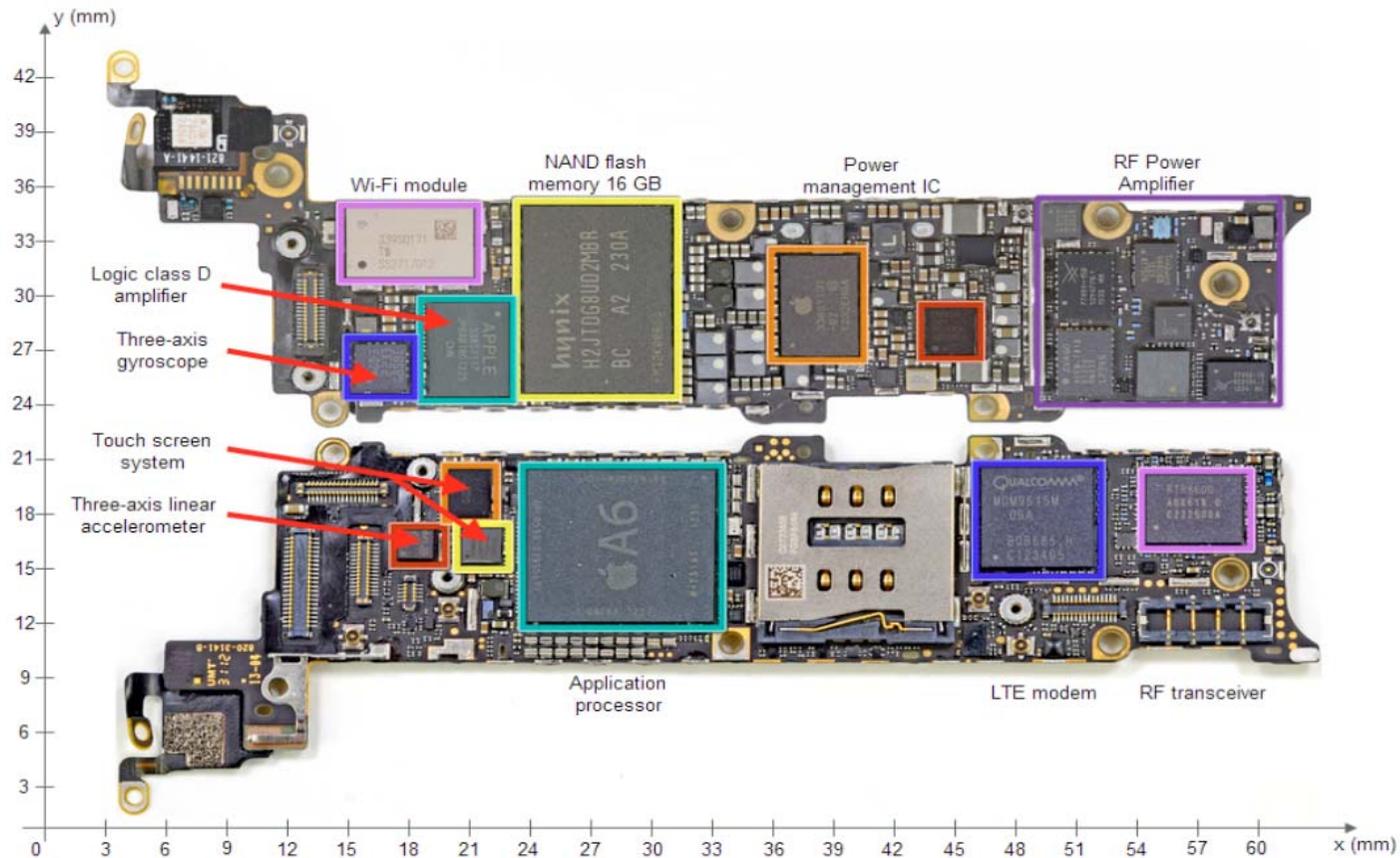
iPhone 5

The smartphone interacts with the surrounding environment through the sensors and the communication interfaces.
Many smartphone applications have been (can be) developed to implement sensing systems and different researchers have been focused their work on the development of systems that use the smartphone as a sensing device.

Smartphone Sensors (2)

➢ The smartphone sensors measure physical quantities and transmit them to the Application Processor through a Digital Interface.

➢ The smartphone includes smart sensors, composed by:

   ✓ the transducer (converts energy from one form into another);

   ✓ the signal conditioning (takes the output of the transducer and converts it into a form suitable for following processing);

   ✓ the ADC (converts electrical analog signal to a digital signal);

   ✓ Digital Interface (which transmits the measured value to AP).

Classification of Smartphone Sensors
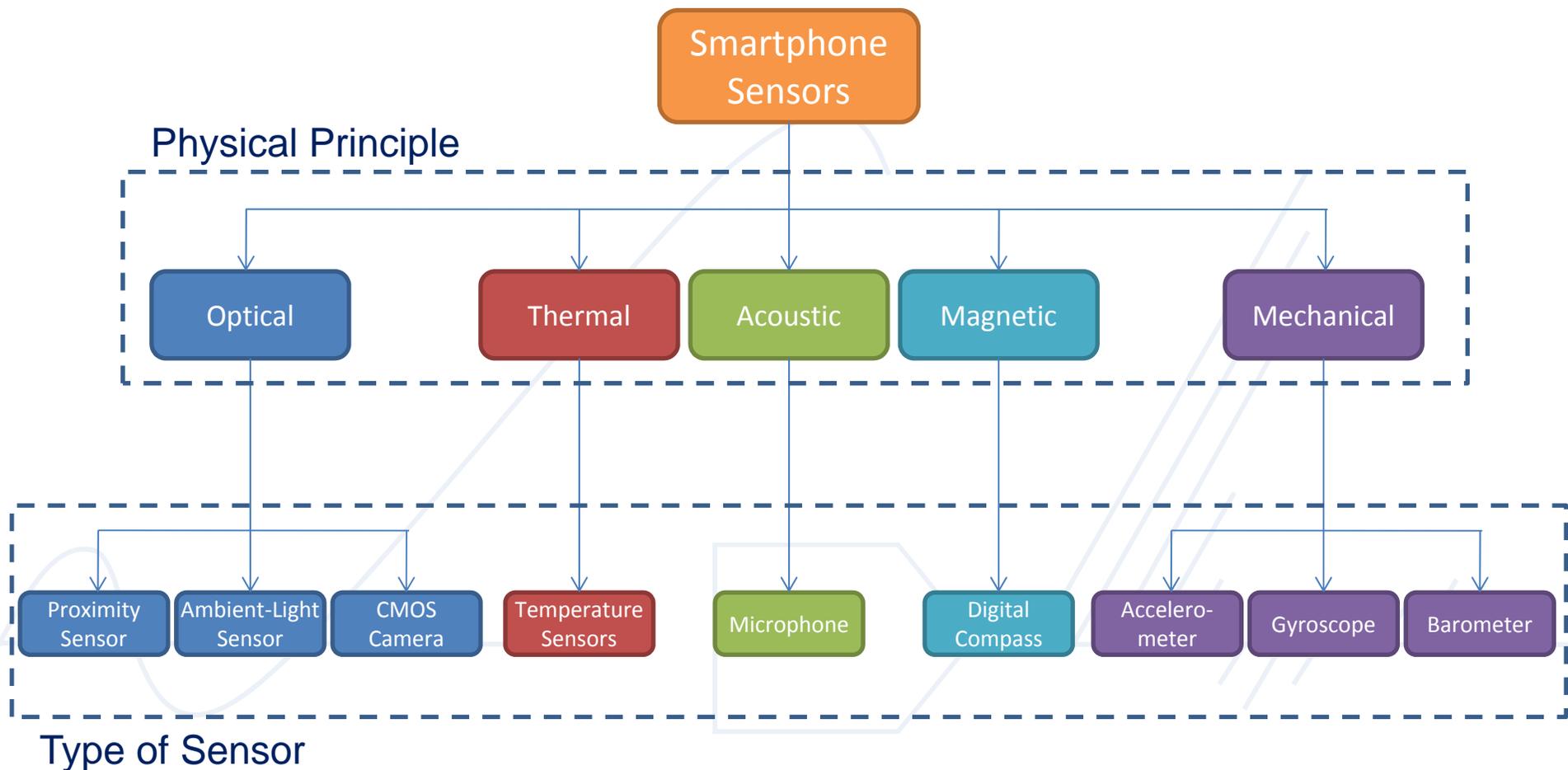
Optical Sensors

➢ The **Optical Proximity Sensor** uses a light emitting diode to send the light beam, which is reflected by an object. A photosensitive diode receives the reflected light, and the object nearby the sensor is detected.

➢ The Ambient-Light Sensor produces a different current proportional to the ambient light intensity. The measured current is used for detecting the ambient light differences.

➢ Another optical sensors is the **CMOS video camera** has the following elements:

  ✓ the lens (collects and focuses the photons on the sensor),

  ✓ the sensor, formed by a color filter array, able to separate red, green and blue light,

  ✓ the ADC,

  ✓ the digital signal processing for color interpolation,

  ✓ the digital interface to communicate the data to AP.

Thermal Sensors

➤ The temperature sensor is used for the thermo control and for the battery management.

✓ The TMP105 produced by the Texas Instruments is an example of temperature sensor. In order to measure and transmit the temperature value to the AP, it uses a diode temperature sensor, a 12 bit ADC and the I2C serial interface.

Acoustic Sensors

➢ The microphone is used mainly for voice calls. For example, iPhone 5 has three microphones and it uses the wideband audio technology in order to improve the speech quality.

➢ By using the microphone, it is possible to detects the sound intensity around you and provides you detailed information about the intensity changes.
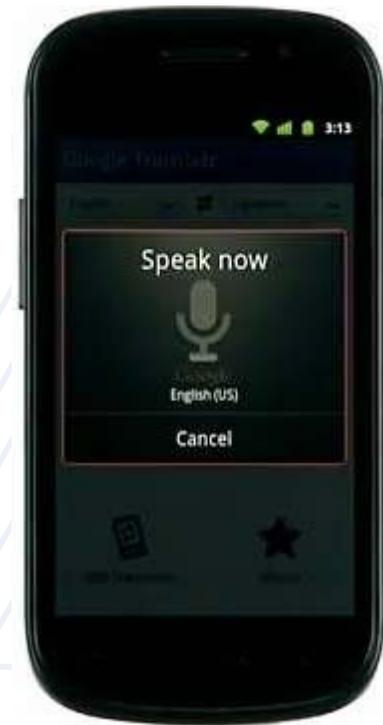
Magnetic and Mechanical Sensors

Magnetic and Mechanical Sensors:

- 3-axis accelerometers
- 3-axis gyroscopes
- 3-axis magnetometers
- Pressure sensors
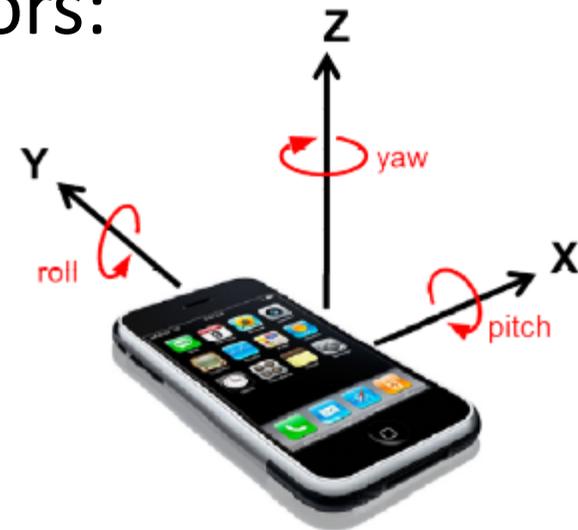
These sensors are based on MEMS (Micro Electro-Mechanical Systems) Technology.

Magnetic and Mechanical Sensors

➤ MicroElectroMechanical Systems (MEMS) are sensors or actuators that contain microelectronics and micromechanical structures.

➤ MEMS are fabricated using techniques similar to those used for integrated circuits. They are micrometer sized mechanical structures, such as cantilevers (e.g. capacitive accelerometer), combs, membranes and channels, that are often integrated with logic circuitry.

➤ The MEMS technology is used in sensor development, especially for accelerometers, gyroscopes and magnetometers design.

➤ MEMS advantages: ultra-small size, low power, low cost, high performance.
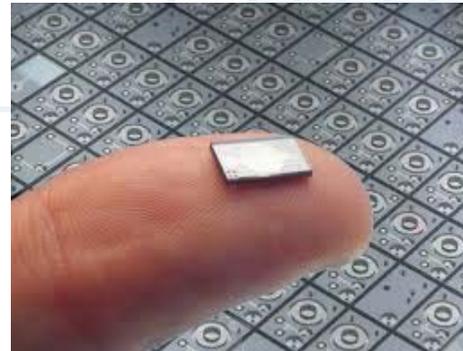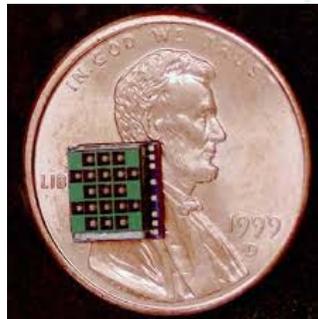
MEMS Advantages

➢ MEMS are an enabling technology transparent in the smartphone

- ✓ Ultra-small form factor
- ✓ Low power
- ✓ Low cost
- ✓ High performance
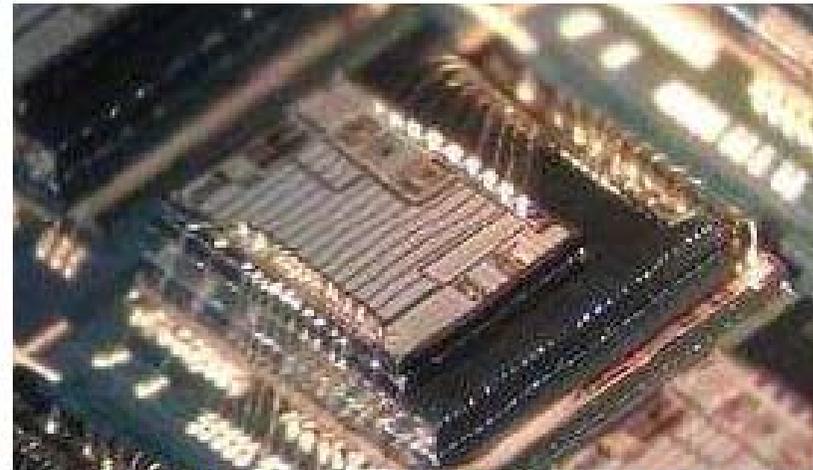
Accelerometers, Gyroscopes, Compasses, Microphones and Pressure Sensors

While the functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics, the most notable (and perhaps most interesting) elements are the microsensors and microactuators that are appropriately categorized as "transducers", which are defined as devices that convert energy from one form to electrical one.

MEMS Motion Sensors – Accelerometer (1)

The LIS331DLH (iPhone 5) is a low power three axes linear accelerometer, having a digital interface produced by STMicroelectronics. It consists of: (i) the capacitive sensing, which converts the acceleration on the three axes in variations of six capacities, (ii) the analog multiplexer (MUX) selects the component for the A/D conversion, (iii) the charge amplifier, converting the capacity charge to a voltage, (iv) the 12 bit A/D converter, (v) the control logic, and (vi) the I2C/SPI digital interfaces.
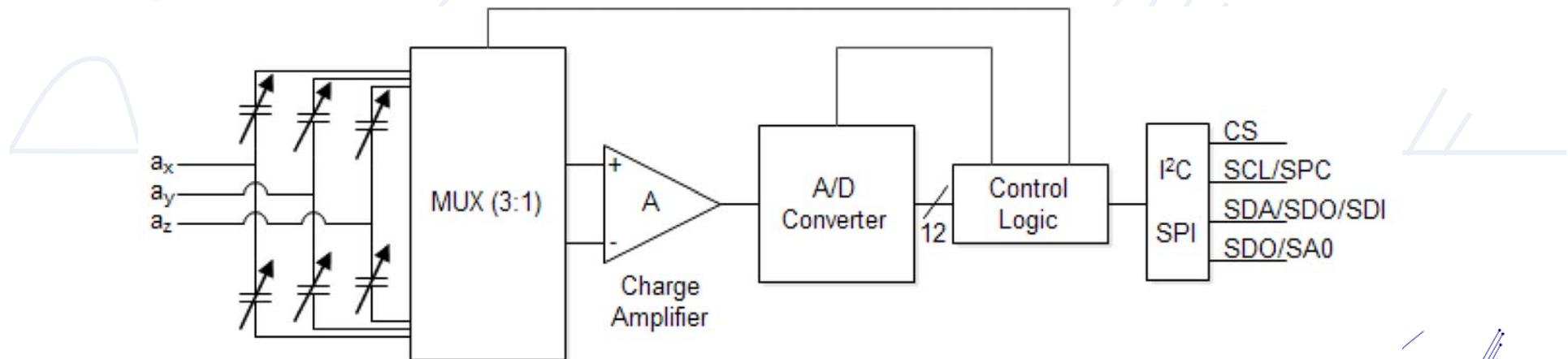
MEMS Motion Sensors – Accelerometer (2)

Symbol	Parameter	Description	Min.	Typ.	Max.	Unit
Mechanical characteristics						
FS	Measurement range	User-selectable		± 2.0		g
				± 4.0		
				± 8.0		
S_o	Sensitivity 12bit	FS = ± 2 g	0.9	1.0	1.1	mg/digit
		FS = ± 4 g	1.8	2.0	2.2	
		FS = ± 8.0 g	3.5	3.9	4.3	
S_{oTC}	Sensitivity vs. temperature	FS = ± 2 g		± 0.01		%
Electrical characteristics						
V_{dd}	Supply voltage		2.16	2.50	3.60	V
I_{dd}	Supply current	Active mode		250		µA
I_{ddSL}		Sleep mode		10		µA
I_{ddPdn}		Power-down mode		5		µA

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MEMS Motion Sensors –Gyroscope (1)

The L3G4200, three-axis gyroscope of iPhone 5, is a low-power angular rate sensor produced by STMicroelectronics, providing on digital output the measurements directly in degree per second (°/s). The internal structure consists of capacitive sensing elements for each axis and a digital interface I2C or SPI for the communication with the AP.
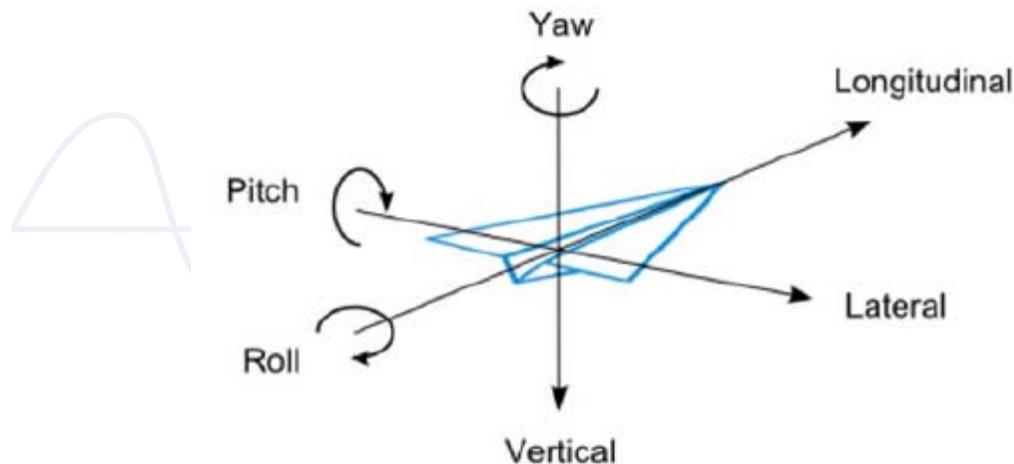
MEMS Motion Sensors –Gyroscope (2)

Symbol	Parameter	Description	Min.	Typ.	Max.	Unit
		Mechanical characteristics				
FS	Measurement range	User-selectable		±250		°/s
				±500		
				±2000		
S_o	Sensitivity	FS=250 °/s		8.75		m°/s/digit
		FS=500 °/s		17.50		
		FS=2000 °/s		70		
S_{oDr}	Sensitivity vs. temperature	From -40 °C to +85 °C		±2		%
NL	Non linearity			0.2		% FS
		Electrical characteristics				
V_{dd}	Supply voltage		2.4	3	3.6	V
I_{dd}	Supply current	Active mode		6.1		mA
I_{ddSL}		Sleep mode		1.5		mA
I_{ddPdn}		Power-Down mode		5		μA

MEMS Motion Sensors – 3-axis magnetometers

➢ Measures the strength of earth's magnetic field
➢ Strength is expressed in tesla [T]
➢ iPhone 4 magnetometer range: ±2mT

Example	Field strength
Earth's magnetic field on the equator (0° latitude)	31 µT
Typical fridge magnet	5 mT
Strong neodymium magnet	1.25 T
MRI (Magnetic resonance imaging) system	1.5 T – 3 T

➢ Applications
  ✓ Compass, of course – rotate maps/interfaces/graphics according to bearing
  ✓ Detect magnets, force fields

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Sensor Data Flow

Firmware Processor

Physical

| Ambient light |
| Barometer |
| Thermometer |
| 3D Accelerometer |
| 3D Gyroscope |
| 3D Magnetometer |

Pass-Through and Calibration

Sensor Fusion

User Sensor

| Ambient light |
| Barometer |
| Thermometer |
| Accelerometer |
| Gyrometer |
| Compass |
| Inclinometer |
| Orientation |

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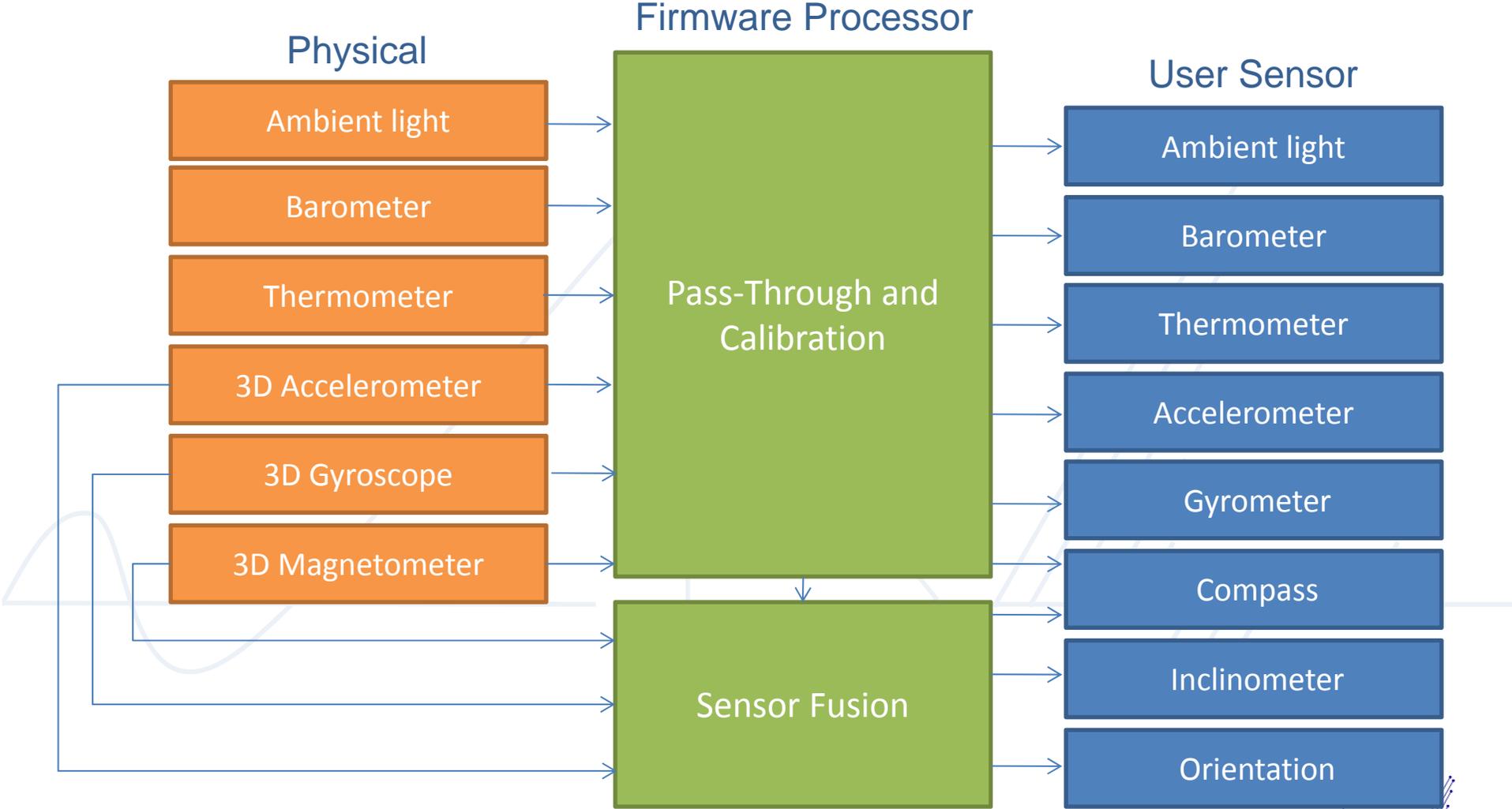
Application Fields

➤ Nowadays, the smartphone can be used in different environments as a stand-alone measurement system.

- ✓ Sport
- ✓ Education
- ✓ Measurement
- ✓ Laboratory
- ✓ Safety
- ✓ Medicine
- ✓ Home automation
- ✓ Urban

➤ These applications take advantage of the embedded sensors of the smartphone or the sensors from an external measurement instrument.

SmartPhone based Measurement Instrument (1)

➢ A SmartPhone based Measurement Instrument (SPMI) can be defined as a mobile general-purpose measurement instrument.

✓ It is mobile because it can be carried or moved easily.

✓ It is general-purpose because it is able to sense different physics quantities.

✓ It is a measurement instrument because it allows:

- *the configuration of measurement setups,*
- *the processing of measured values,*
- *to display the measurement results to the user.*

P.Daponte, L.De Vito, F.Picariello, M.Riccio, **State of the Art and Future Developments of Measurement Applications on Smartphones**, Measurement, vol. 46, Issue 9, Nov. 2013, pp.3291–3307..

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SmartPhone based Measurement Instrument (SPMI)

The smartphone can be used as a measurement instrument as it has the hardware capabilities, such as sensors and wired or wireless interfaces, in order to measure physical quantities and the OS to manage the whole hardware platform, for processing the measured values and for interacting with the user.

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Embedded SPMI

➢ The smartphone acts as an **Embedded SmartPhone based Measurement Instrument (ESPMI)** if it receives the measured value directly from its embedded sensors.
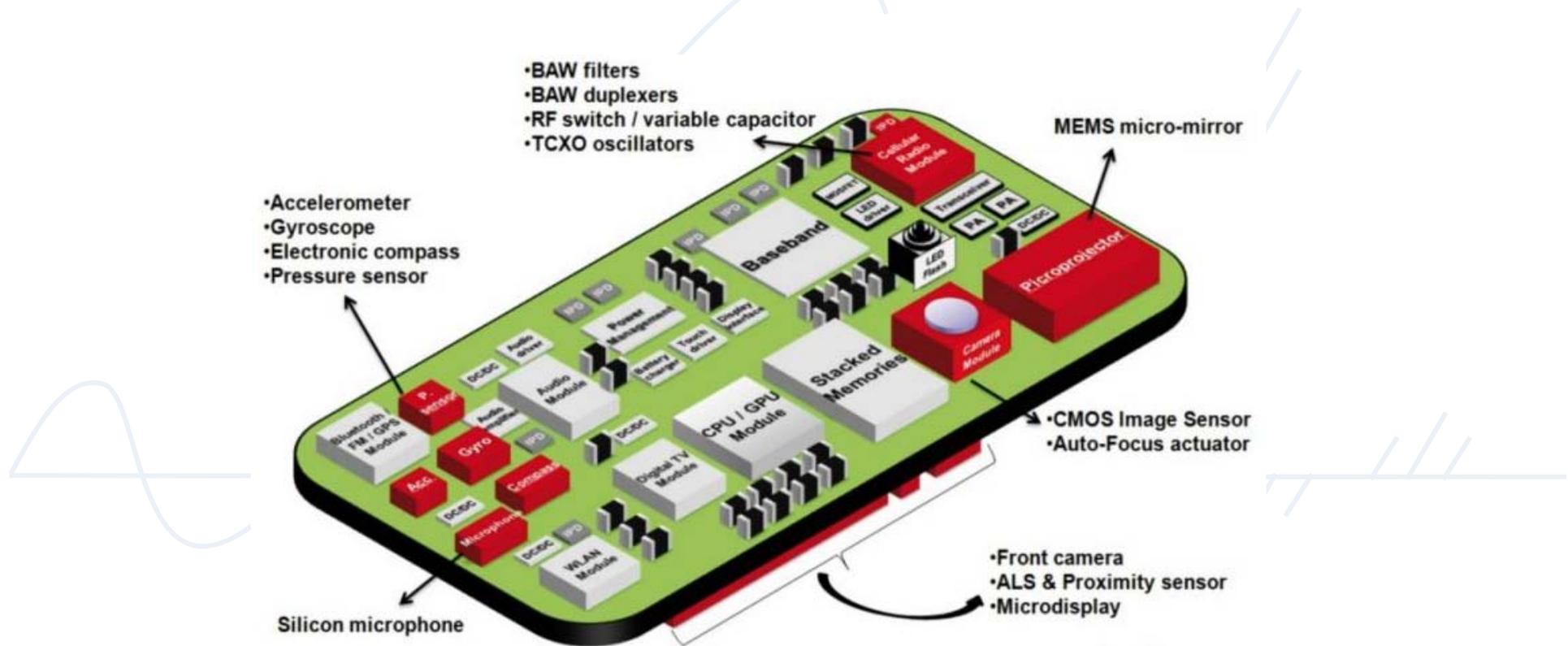
SmartPhone based Measurement Instrument (SPMI)

SPMI Interface (1/2)

The smartphone acts as a **SmartPhone based Measurement Instrument Interface (SPMII)** if it receives from an external measurement instrument the measured value and shows it to the user.

SmartPhone based Measurement Instrument (SPMI)

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SPMI Interface (2/2)

➢ When the smartphone is used as a **SmartPhone based Measurement Instrument** it has different roles:

  ✓ to communicate with the sensors in order to receive the measured values,

  ✓ to implement a user interface, and

  ✓ to communicates with external devices via wireless.

SmartPhone based Measurement Instrument (SPMI)

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Person Oriented or Outside Oriented

SmartPhone based Measurement Instrument (SPMI)

➢ Applications of smartphones can be divided in person oriented and outside oriented.

- ✓ The **person oriented applications** use the SPMI to measure physical or behavioral user parameters (e.g. heart rate, pressure, blood flow, exercise performances, etc.),
- ✓ The **outside oriented applications** measure quantities external to the user (e.g. traffic and road conditions, whether conditions, electrical and electronics measurements, etc.).

Embedded SmartPhone based Measurement Instrument (ESPMI)

Person oriented applications

Examples

L.E.S.I.M.

ESPMI - Detect heart beat rate

P.Pelegris, K.Banitsas, T.Orbach, K.Marias, "A novel method to detect heart beat rate using a mobile phone", Proc. of Annual Int. Conf. of the IEEE Engineering in Medicine and Biology Society, 31 Aug. - 4 Sept., Buenos Aires 2010, pp.5488-5491.

➢ Runtastic Heart Rate

➢ Cardiograph

A medical application to detect the heart rate using a smartphone video camera is presented. It exploits the color change of the skin, as a result of a cardiac pulse. In order to measure the heart rate, the user puts the finger over the smartphone camera. In this way, the camera captures video frames and a gray scale analysis of a portion of the image is applied. The system extracts an average brightness value for each frame that turns out to be lower when the finger capillaries are full of blood, whereas it increases as the blood retreats. The average brightness values for each frame are stored with their time stamps. By counting the number of peaks of the brightness values in a time interval, it is possible to estimate the count of beats per minute (bpm).

ESPMI - GymSkill Personal trainer

➤ Monitoring and assessment of physical exercises

  ✓ Based on phone sensor data
  ✓ No need for additional sensors
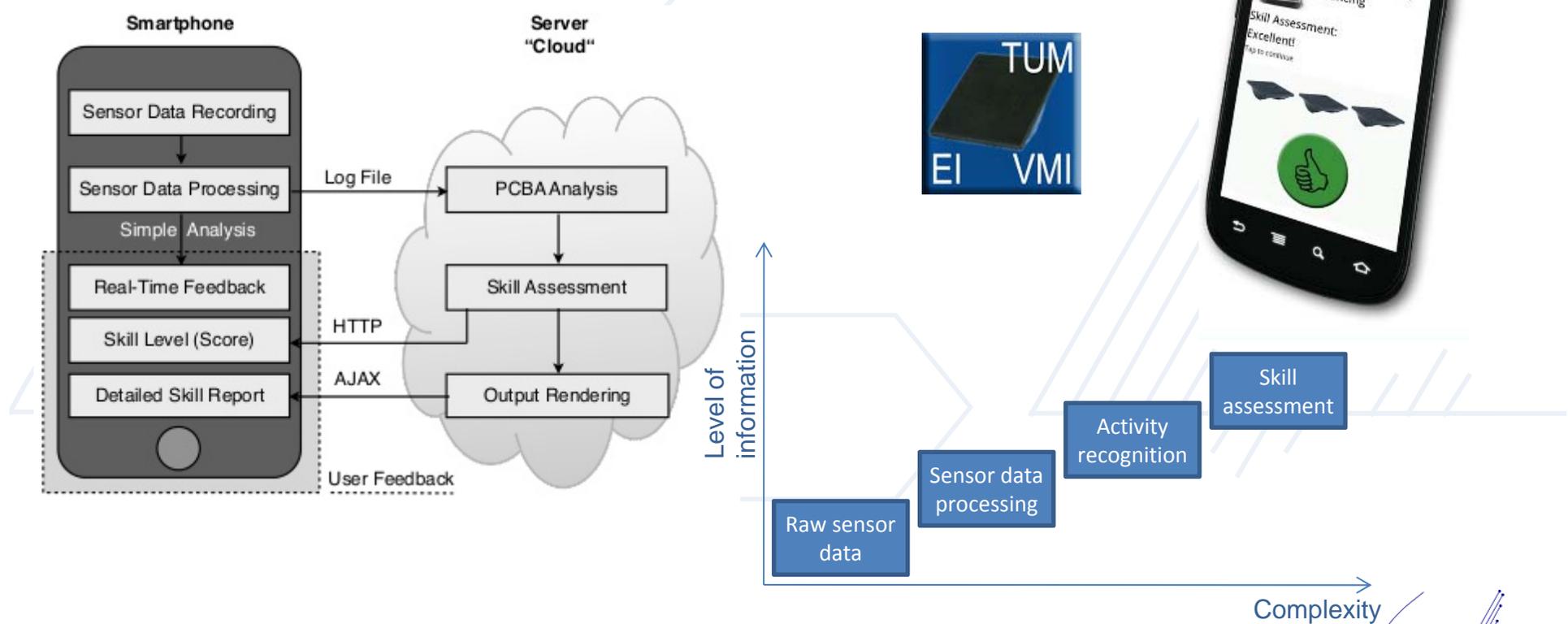
Kranz, M., Möller, A., Hammerla, N., Diewald, S., Plötz, T., Olivier, P. & Roalter, L. "The mobile fitness coach: towards individualized skill assessment using personalized mobile devices", 2013 In : Pervasive and Mobile Computing. 9, 2, pp. 203–215. 13 p.

ESPMI – Recognition Of Aggressive Driving

➢ This system recognizes the driving style in order to detect potential dangerous situations.

➢ By using the smartphone, one can to classify the driving style in aggressive and non-aggressive.

➢ MIROAD uses the following smartphone sensors: rear-facing video camera, 3-axis accelerometer, 3-axis gyroscope, digital compass and GPS.

➢ The gyroscope signals indicate the vehicle turn movements, while the accelerometer, magnetometer and gyroscope signals are used to estimate the vehicle orientation.

➢ The system can detect the following events on driving style: aggressive right turn, aggressive left turn, aggressive U-turn, aggressive acceleration, aggressive braking, aggressive lane change and high speed.

D.A.Johnson, M.M.Trivedi, "Driving style recognition using a smartphone as a sensor platform", Proc. of 14th Int. IEEE Conference on Intelligent Transportation Systems (ITSC), 5-7 Oct. Washington, DC 2011, pp.1609-1615.

Embedded SmartPhone based Measurement Instrument (ESPMI)

Outside oriented applications
Examples

ESPMI – Metal Detector

➢ This app measures magnetic field values using the magnetic sensor that is built into the phone.

➢ The magnetic field level (EMF) in nature is about 49µT (microtesla) or 490mG (milligauss); 1µT = 10mG.

➢ If there is any metal in the area, the strength of the magnetic field should increase. Among other uses, it can be helpful in finding electrical wires in walls and metal in the ground.

ESPMI – Wind Speed Meter

➢ Wind Speed Meter is sound based anemometer to estimate wind speed.

➢ It works by analyzing the sound of wind passing the device microphone.

➢ Wind Speed Meter includes compass integration, so you can easily find wind direction too.

➢ It supports multiple units of measure including MPH, Knots, Km/h, m/s and dynamic Beaufort scale.

➢ There is an ability to calibrate your phone model to obtain more accurate results.

➢ This application is not meant to be used in place of scientific instrumentation, but it can come close to real anemometer device.

➢ Wind Meter is ideal for Windsurfing, Kitesurfing, Kiteboarding, Snowkiting or Gliding.

http://www.new-itechnologies.com/

WSM

A/D
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ESPMI - Measuring the object dimensions

➢ It is an easy to use and handy telemeter measure tool for object length, width, size, angles, area and dimensions measurements that can be used as a ruler, tape measure or planimeter.

➢ It uses the phone camera and any available object with known size as a reference. Most common reference objects like credit card, sheet of paper, DVD/CD, etc. are included in the application. Custom objects with known size can be used to do camera measure.

➢ If your friend or colleague is next to you, you don't need a ruler: just use his height as a reference and measure objects around you.

➢ You can use the app in medical area: for example, to measure distance between pupils by holding a credit card next to your face.

http://www.vistechprojects.com/
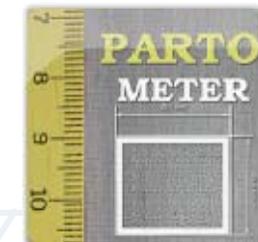
SmartPhone based Measurement Instrument Interface (SPMII)

Person oriented applications

Examples

SPMII – Glucose meter

➢ **iBGStar is the first available blood glucose meter for iPhone**

✓ Blood glucose meters typically measure the glucose in your blood by sending an electrical signal through a blood sample. This signal is then returned to the blood glucose meter as an output signal to be processed into a numerical glucose level.

A/D
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SPMII – Array of sensors for Healthcare

➤ One-lead ECG

➤ Body temperature

➤ Blood glucose

➤ Heart rate

➤ Blood oxygen saturation

➤ Body fat percentage

➤ Stress level

www.sensorcon.com/sensordrone/

SPMII – Wearable Sensors

Respiration Band

ECG, Respiration, GSR, 3-axis accelerometer, Ambient and skin temperature

Electrodes

Temperature Probe

Alcohol, PPG sensor in arm band

L.E.S.I.M.

SmartPhone based Measurement Instrument Interface (SPMII)

Outside oriented applications

Examples

A/D

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SPMII – Temperature & Humidity Sensor

➢ iCelsius RH

✓ Temperature range
-40° to +120°C

✓ Accuracy ±0.5 °C,
0-100% RH+2%

SPMII – Agilent Mobile Meter

➢ Agilent Wireless Remote Connectivity solution improves your work efficiency and safety.

➢ Connect wirelessly to your Agilent U1200 series handheld digital multimeters or clamp meters via Bluetooth® wireless technology.

➢ The Agilent Mobile Meter enables you to view measurements from up to three Agilent handheld meters, extending your reach wirelessly to multiple points from a single location.

➢ Make measurements from a safe distance and eliminate the need to walk back-and-forth between measured points and control panel during trouble shooting.

SPMII – Sensordrone

13 different sensors:
from gas oxidization
to color intensity
measurement

http://www.sensorcon.com/sensordrone/
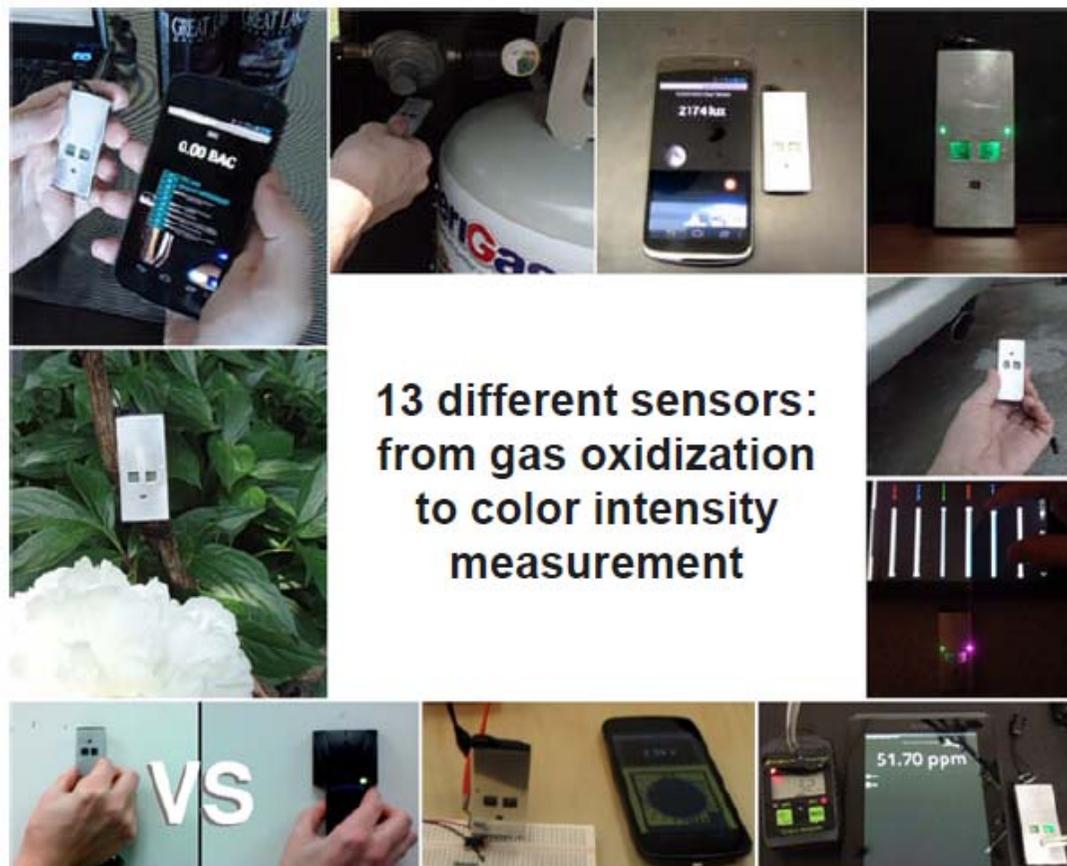
SPMII – pH Sensor for Smartphone

PH-1 pH Meter
for iPhone and iPad

http://www.sensorex.com/

SPMII – Chemical Sensors (1)

✓Carbon monoxide

✓Chlorine

✓Ammonia

✓Methane

✓Blood sugar

✓Etc.
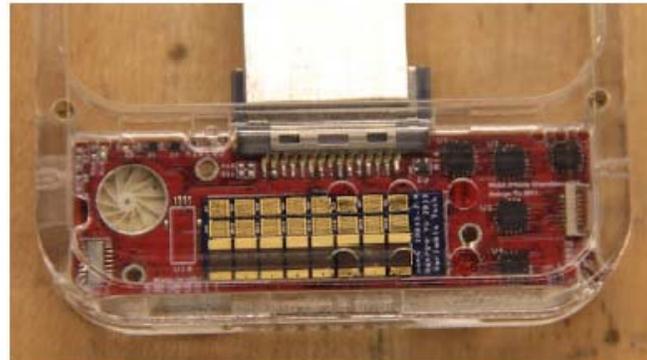
Postage-sized chip with 32 nanosensor bars

SPMII – Chemical Sensors (2)

➤ It can detect killer gasses in the air.

➤ While the concept is not new, this prototype is fully working and operational. Created by Jing Li and a team of researches at NASA's Ames Research Center, Moffett Field, California.

➤ The latest-generation of the multiple-channel silicon-based sensing chip, which consists of 64 nanosensors, and is less than one square centimeter. Each side has 16 nanosensors – all that is required for cell phone use.
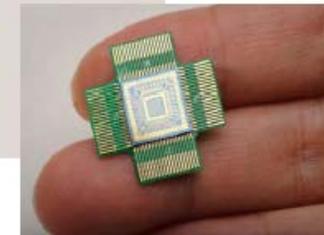
http://www.nasa.gov/centers/ames/news/features/2009/cell_phone_sensors.html

SPMII – Dosimeter-Radiometer

The application ensures uninterruptible monitoring of radioactive background in radiometer mode. When used as a dosimeter, the application performs preliminary assessment of annual exposure.

Assessment of safety level is based on radiation safety standards NRB-99/2009 and Sanitary Regulations and Standards SanPin 2.6.1.2523-09.

http://intersofteurasia.ru

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How to make smartphones even more smarter?

Smartphone even more as a measurement station

Optimize smartphone as a measurement station

- ➤ **Sensor Hub Microcontroller for Smartphones**
  - ✓ Low power microcontroller for various sensors on smartphone
- ➤ **Universal Sensors & Transducers Interface**
  - ✓ Multi-sensor system for smartphone
  - ✓ Sensors compatibility, drivers and firmware
- ➤ **New Processing Solutions**
  - ✓ Selection and integration of sensor data processing in consumer apps
  - ✓ Augmented Reality

Sensor Hub Microcontroller for Smartphones (1)

➤ Sensors are controlled by the low power microcontroller.
➤ Reduction of load on the host processor.
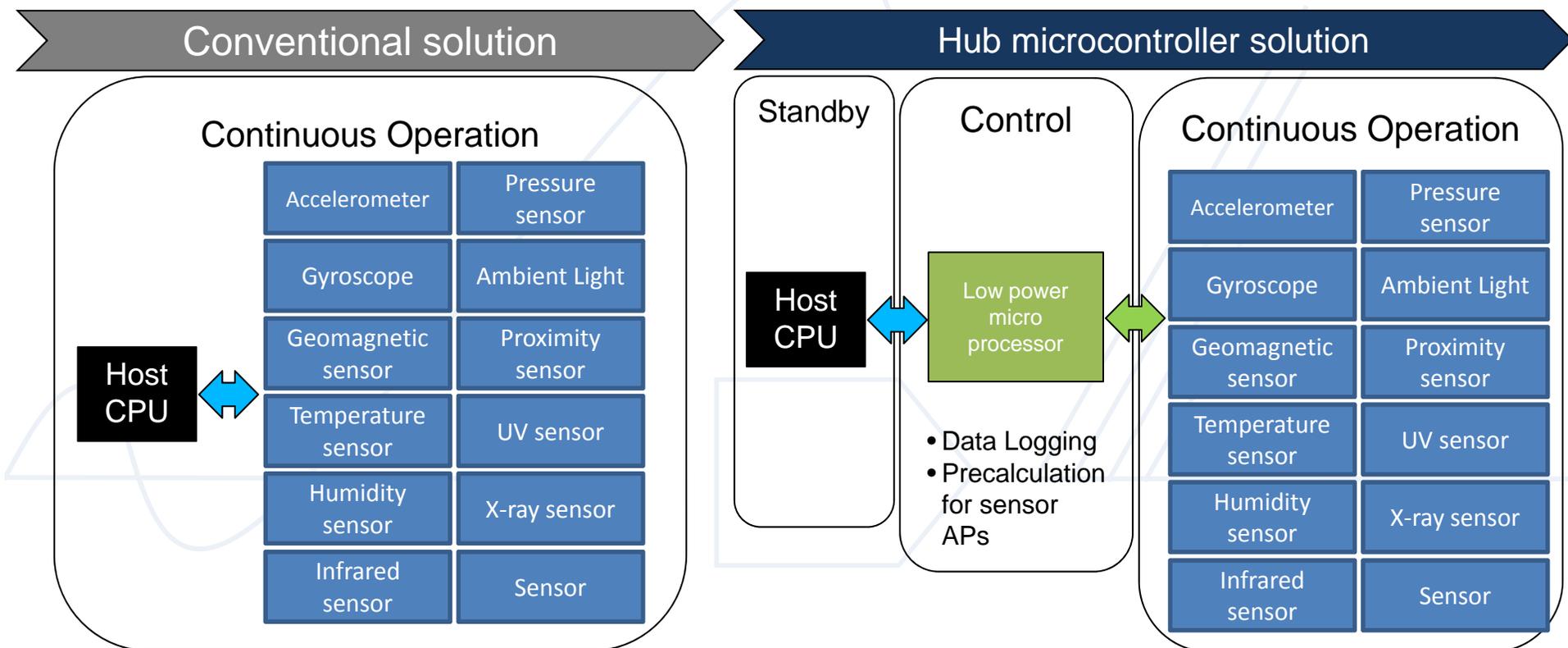
Independent sensor control without host CPU

Sensor Hub Microcontroller for Smartphones (2)
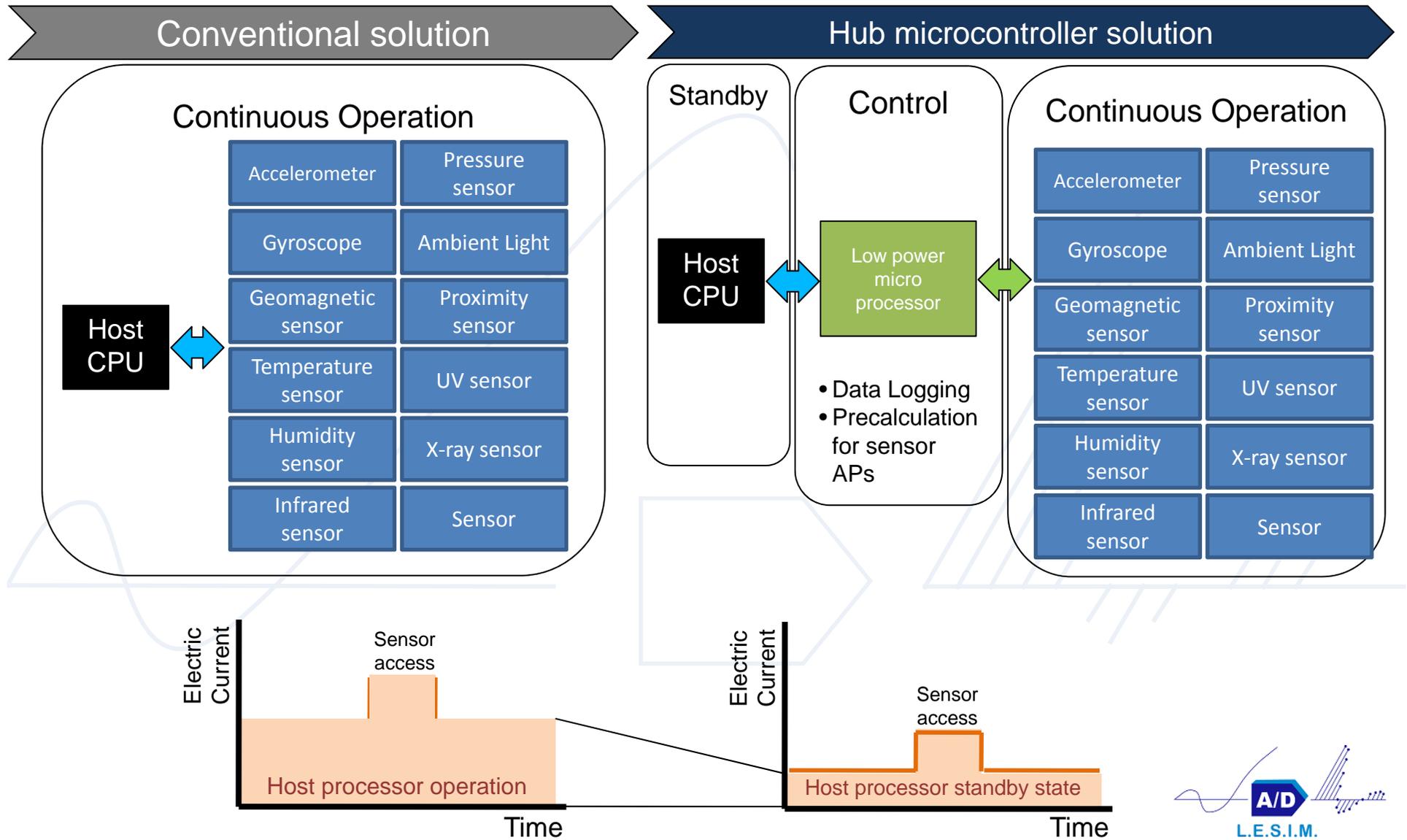
Sensor Hub Microcontroller for Smartphones (3)

Conventional solution

Hub microcontroller solution
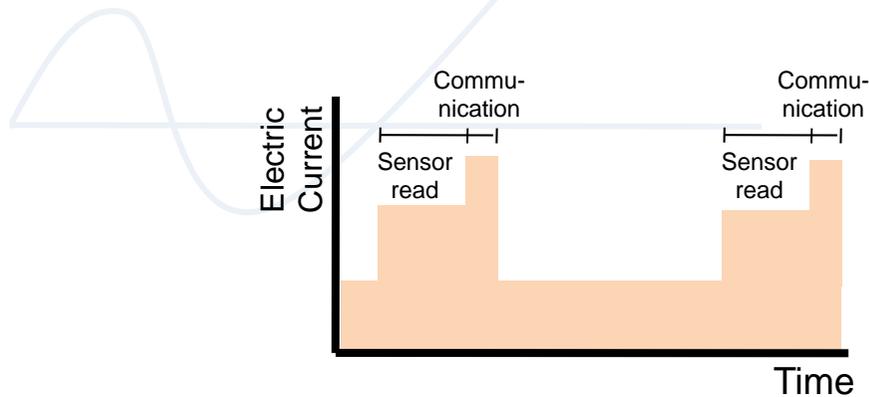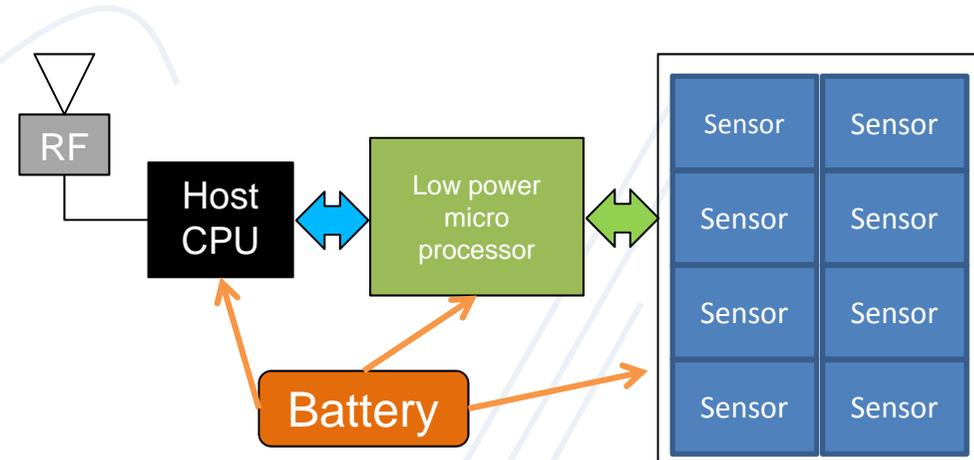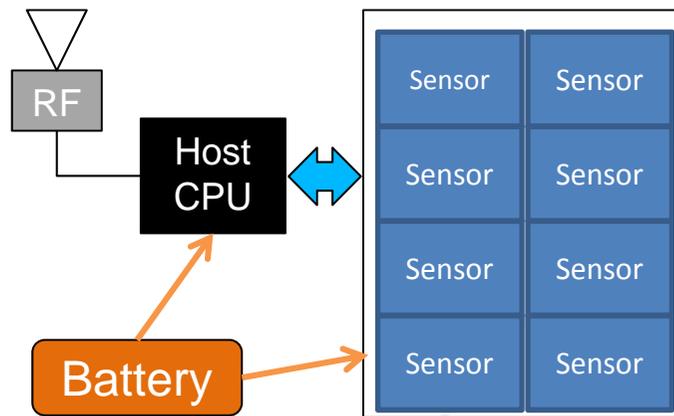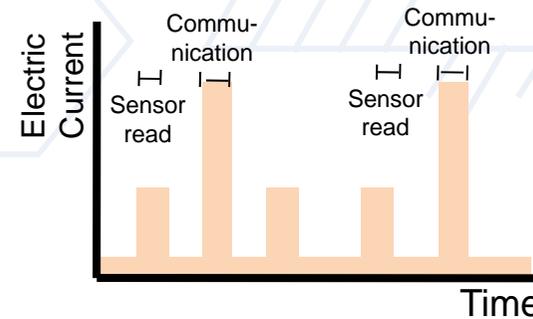
Universal Sensors & Transducers Interface (1)

➢ New generation of cost effective smart and intelligent multisensor systems.

➢ Large application potential in sensor technology.

➢ Digital sensors with wide functionalities including such intelligent functions as self-adaptation and self-identification.

➢ Developed advanced technologies and novel electronics components give a unique opportunity to create and produce various, and robust sensor systems with high metrological performances.

New processing solutions

➢ The increasing number of measurement applications on smartphones is due to their capabilities of

  ✓ sensing more and more physical quantities, so that new measurements can be carried out as a fusion of different measured values from new embedded sensors on the smartphone

  ✓ offering wider wireless and wired connection possibilities and smart visual interfaces in order to receive measurements from different systems external to the smartphone.

JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement
data — Guide to the expression
of uncertainty in measurement

Évaluation des données de mesure —
Guide pour l'expression de l'incertitude de
mesure

First edition September 2008

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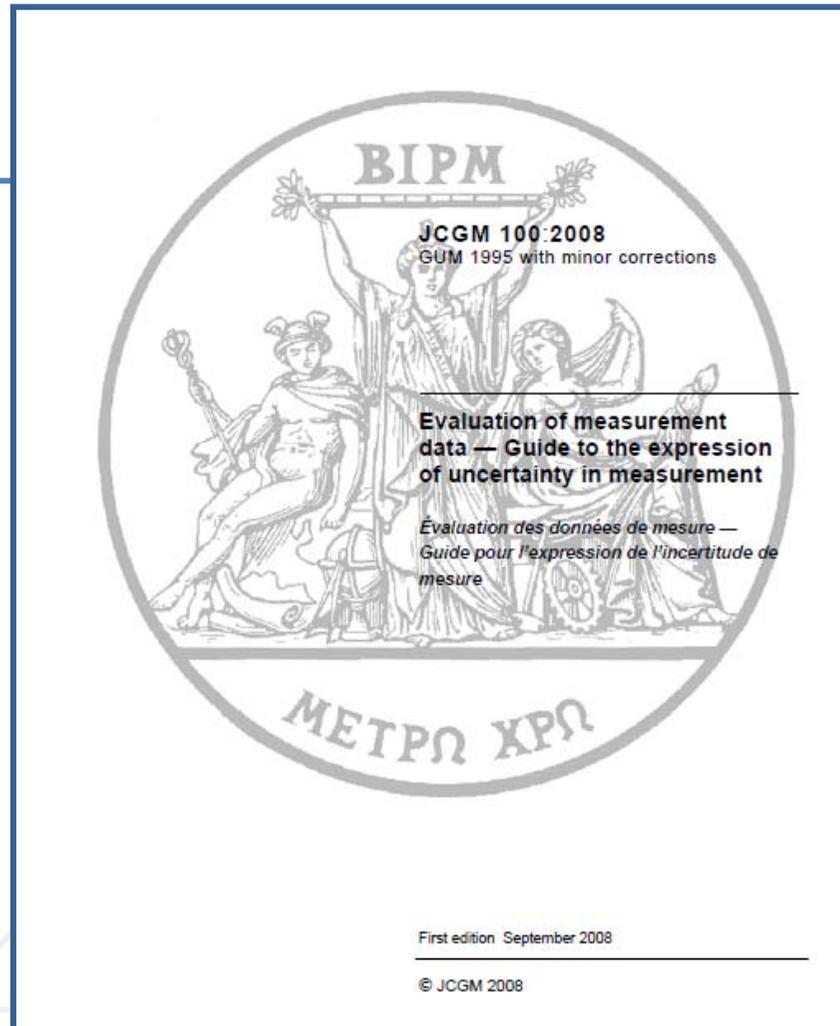
Are the measurements provided by the
smartphone traceable and repeatable?

Measurement uncertainty (2)

➢ Many applications use the data from sensors without knowing the accuracy.

➢ It is necessary to calibrate the smartphone sensors and to characterize them from the measurement point of view for taking measurements traceable, repeatable and usable.

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Measurement uncertainty (1)

➢ The GUM is widely acknowledged as best practice in the calculation of uncertainty.

➢ The uncertainty can be provided evaluating the standard deviation of the measurement.

➢ Procedure for evaluating the uncertainty of a 3-axis accelerometer:

  ✓ Autocalibration algorithm for the compensation of systematic effects;

  ✓ Evaluation of the measurement standard deviation;

  ✓ Evaluation of the measurement uncertainty.

M.G.D'Elia, A.Del Giudice, G.Graditi, V.Paciello, "Measurement uncertainty on smart phone" IEEE Conf. on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), pp.144-149, 15-17 July 2013

New processing solutions - Examples

Example - Smartphone & measurements in the medical field

➢ Measurement of the Knee Flexion Angle With a Smartphone-Application is Precise and Accurate, The Journal of Arthroplasty, vol.28, No.5, May, 2013, pp. 784-787.

➢ Use of the iPhone for Cobb angle measurement in scoliosis, European Spine Journal, vol.21, No. 6, June, 2012, pp. 1062-1068.

➢ Inter- and intra-observer reliability of a smartphone application for measuring hallux valgus angles, Foot and Ankle Surgery, vol.19, No.1, March, 2013, pp. 18-21

➢ Characterization of a Smartphone Camera's Response to Ultraviolet <fc>A</fc> Radiation, Photochemistry and Photobiology, vol.89, No.1, January 1, 2013, pp. 215-218

➢ Within-day reliability of shoulder range of motion measurement with a smartphone, Manual Therapy, vol.17, No. 4, August, 2012, pp. 298-304

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Smartphones & Augmented Reality
What is Augmented Reality?

Augmented reality

Augmented virtuality

Real environment

Virtual environment
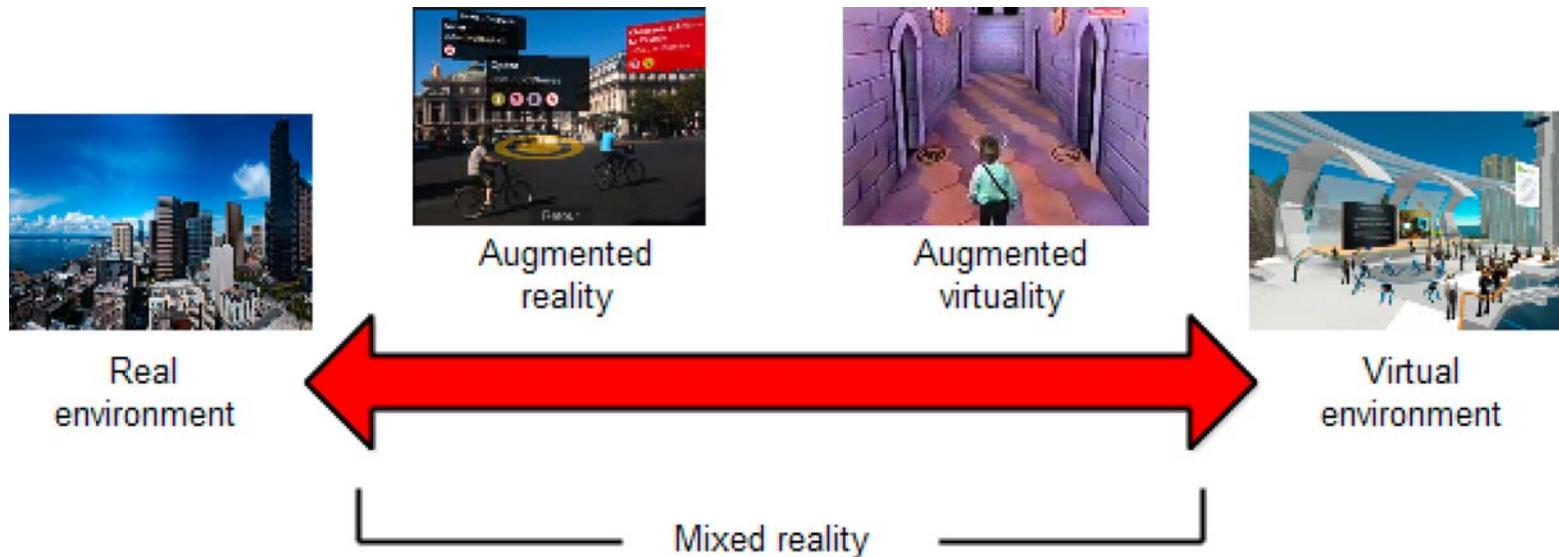
Mixed reality

➢ Milgram's reality-virtuality continuum:
  ✓ AR is a part of the mixed reality
  ✓ AR is based on a real environment with added computer generated virtual objects
  ✓ AR is the enrichment of the human sensorial perception

A/D
L.E.S.I.M.

Smartphones & Augmented Reality
What is Augmented Reality?

Dimension of Artificiality

synthetic (generated from computer data)

physical (generated from the real world)

Augmented Reality

Virtual Reality

Physical Reality

Tele-Presence

Dimension of Transportation

local (remain in the physical world)

remote (leave your body behind)
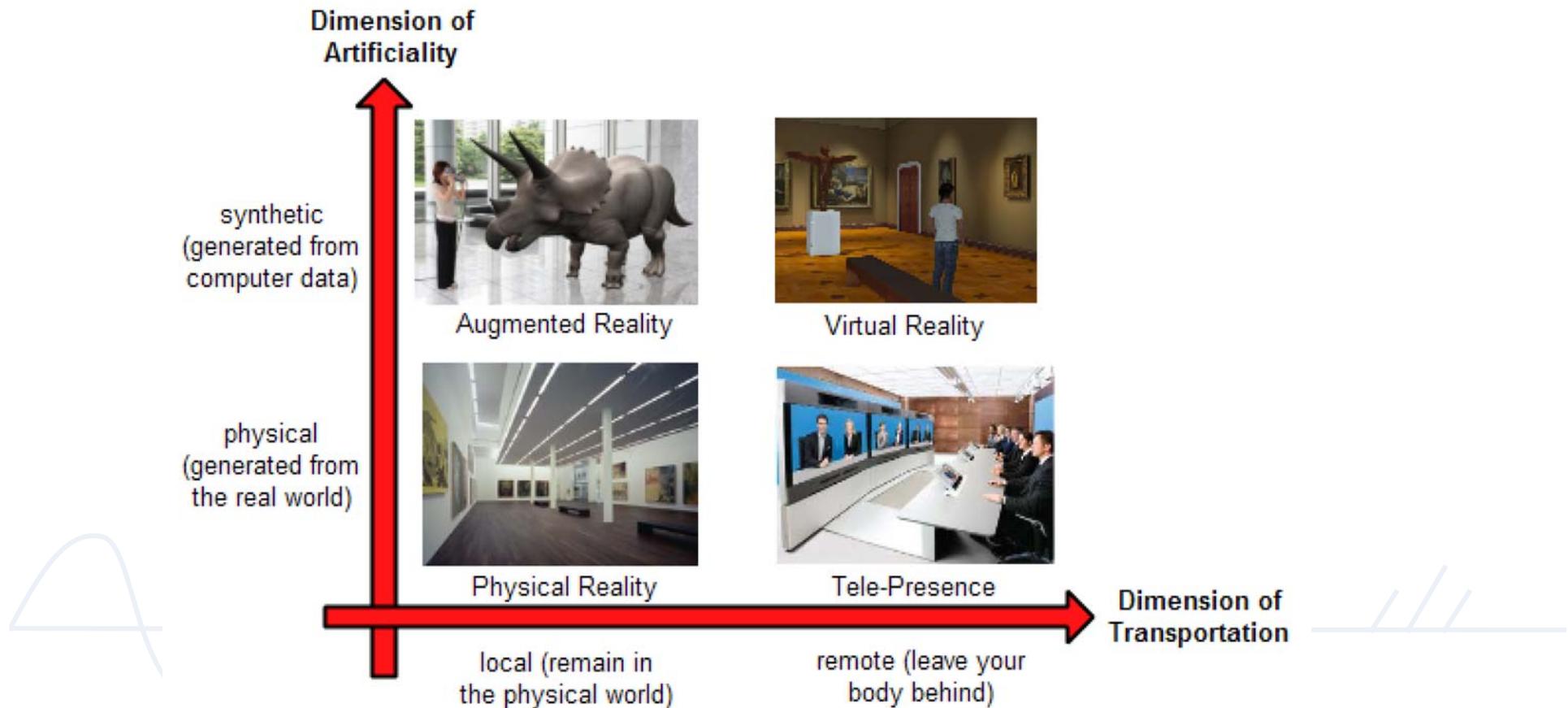
Benford's AR definition: "AR combines a local transportation level with virtual environment"

A/D
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General architecture of an AR system
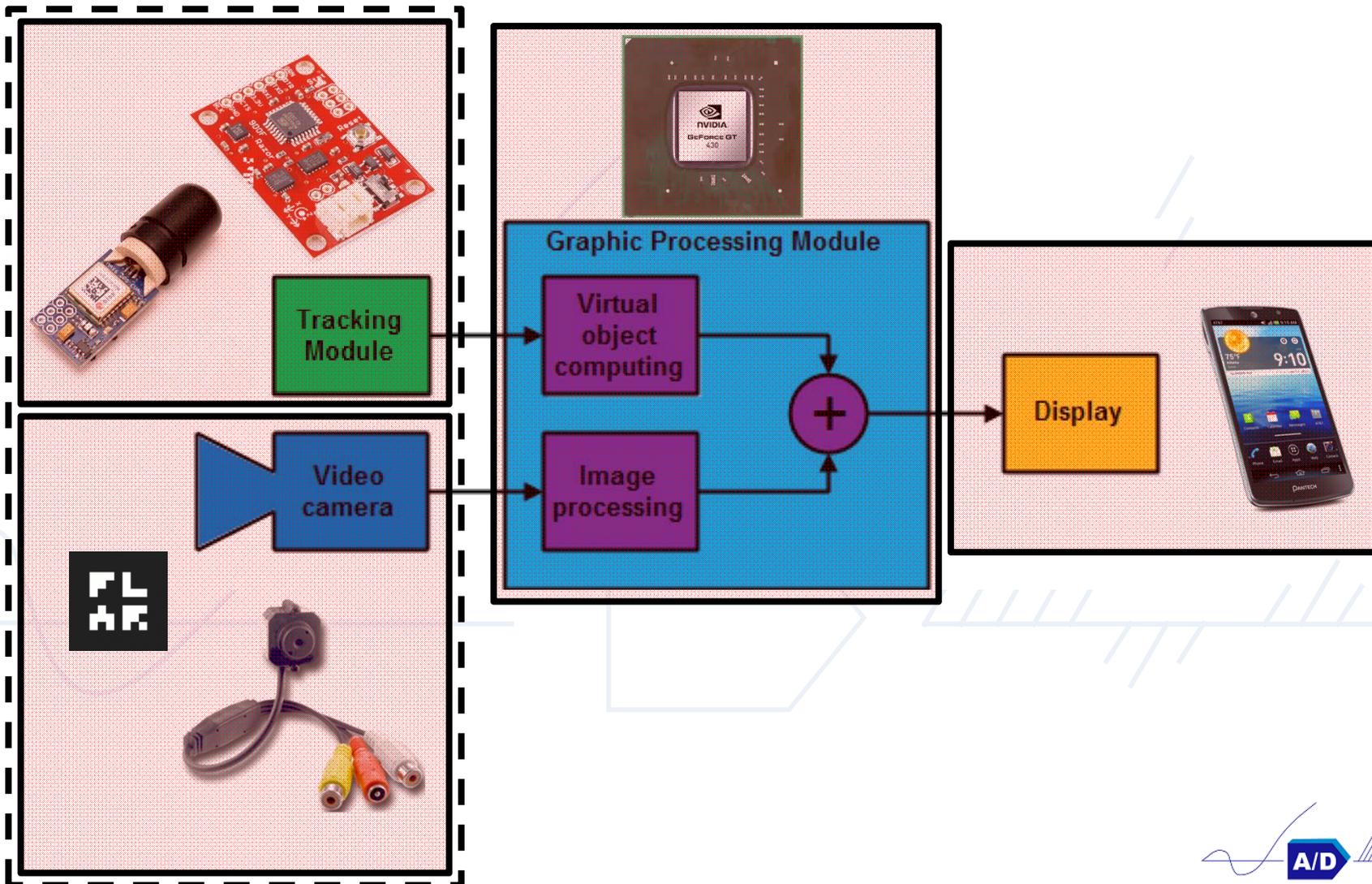
Smartphones & Augmented Reality

➢ A Mobile Augmented Reality system:
  - ✓ overlaps virtual objects on an image captured from a video camera
  - ✓ permits to the user to interact with virtual object
  - ✓ is based on real-time processing
  - ✓ is based on IMU, GPS receiver and video camera
  - ✓ requires GPU (Graphics Processing Unit)

Smartphones & AR (Nexus 5)
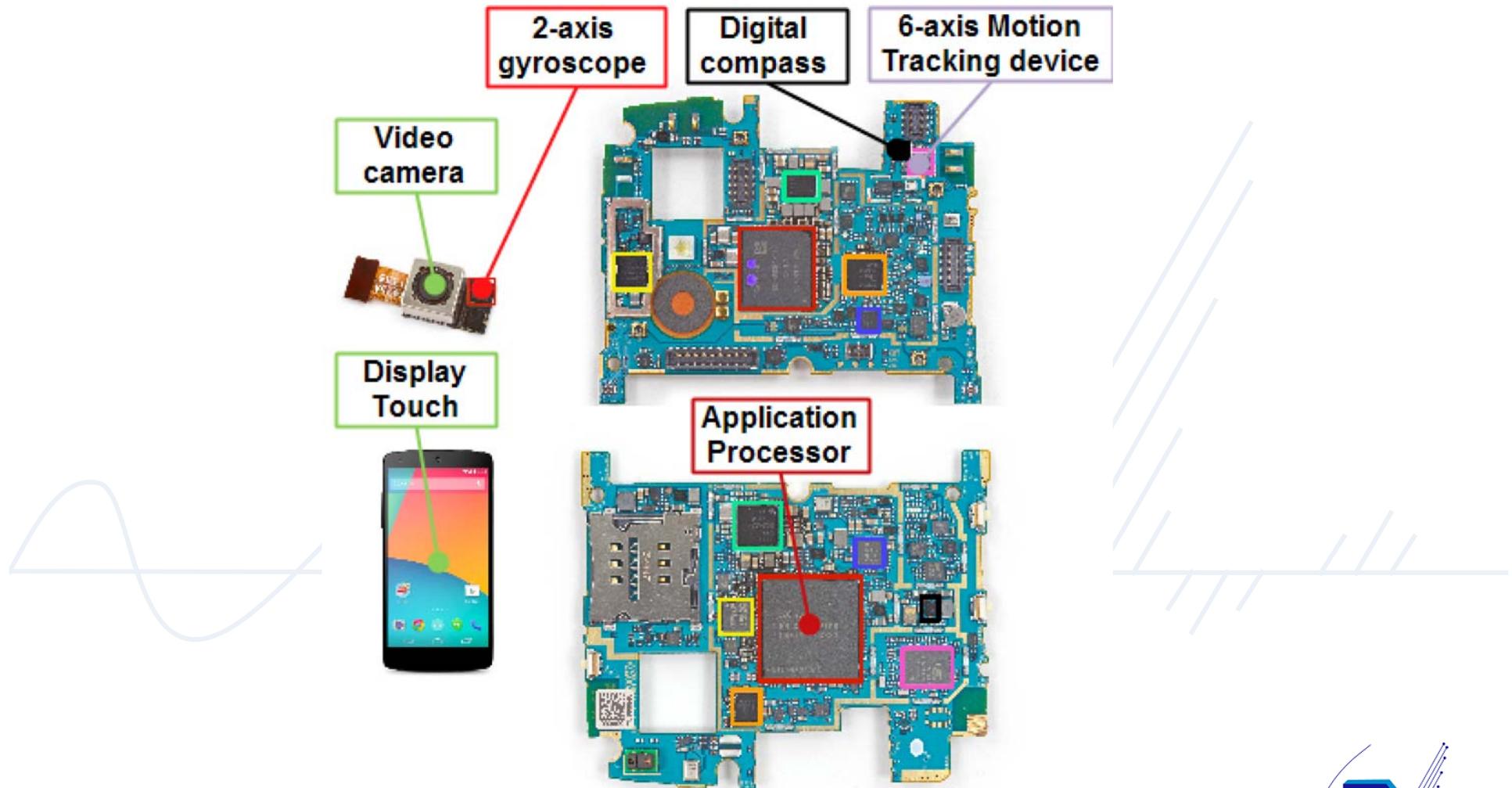
Tracking module

➢ It measures the relative position of the camera in real time

➢ It measures the position of objects in the real environment

➢ It allows the correct positioning of virtual objects on the real scene

Video camera   Fiducial markers   GPS module   IMU
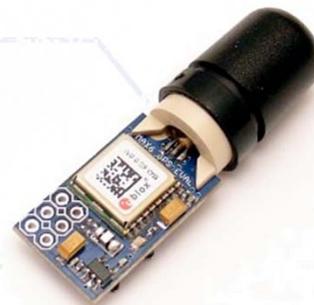
Graphic Processing Module

➢ It uses the images captured from the video camera

➢ It uses the measurements provided by the tracking module

➢ It generates virtual objects

➢ It combines the real image with the virtual contents

GPU
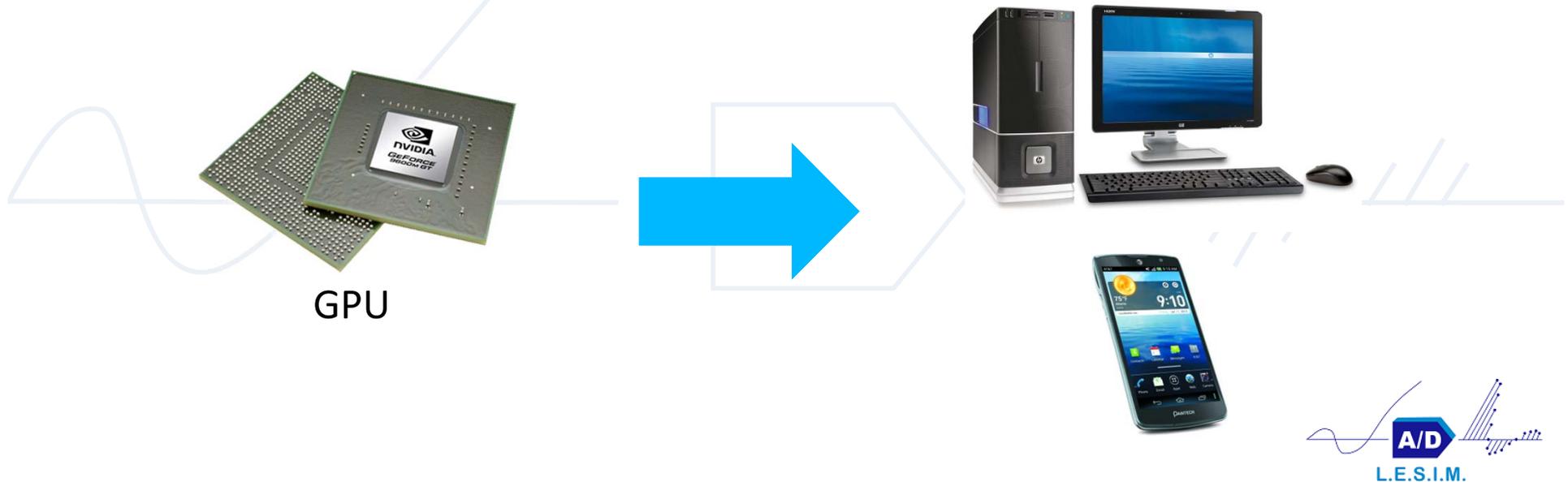
Display

The computed images are rendered to the user through the display
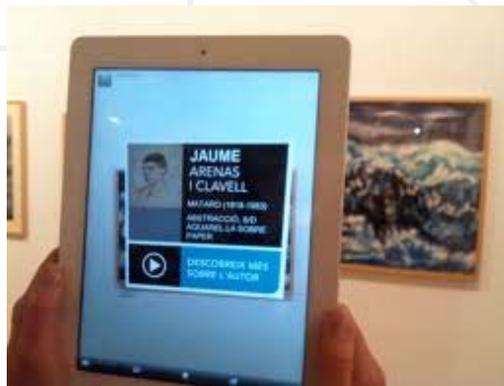
The measurement science has a fundamental role for AR systems, why?
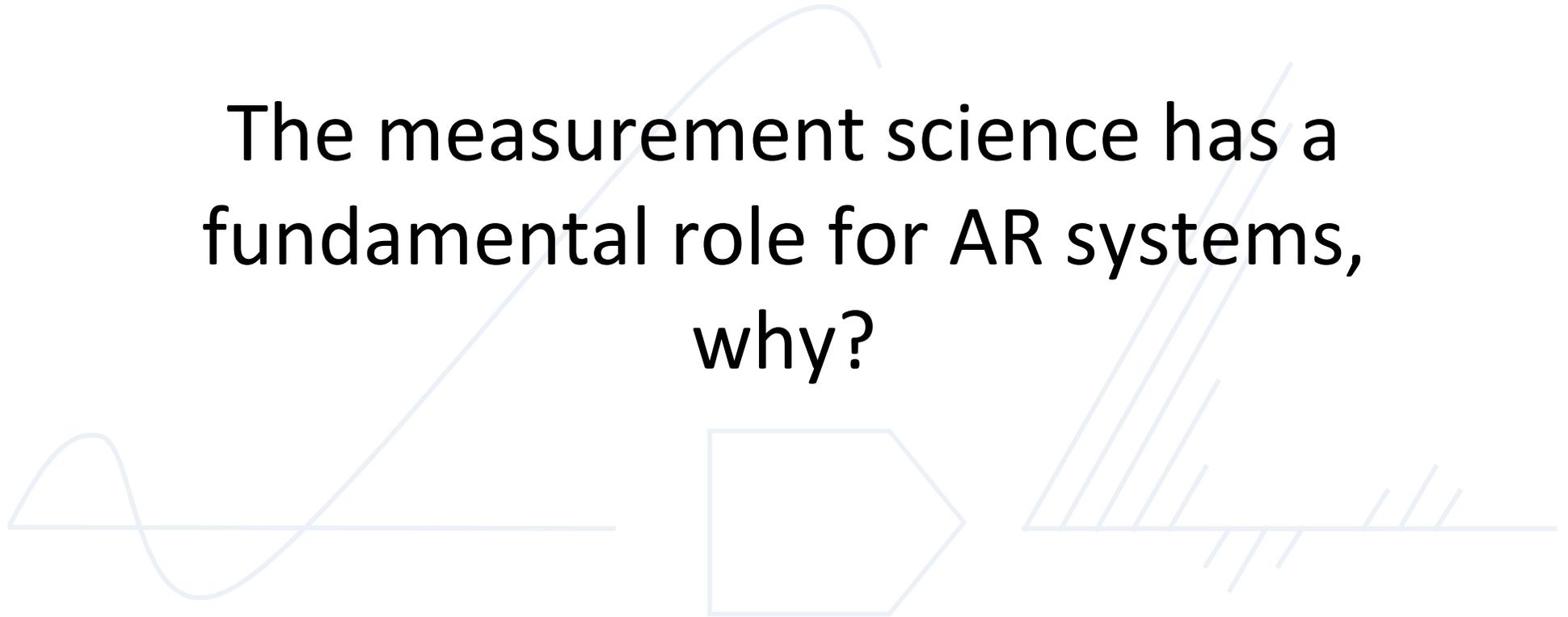
Measurements for AR systems
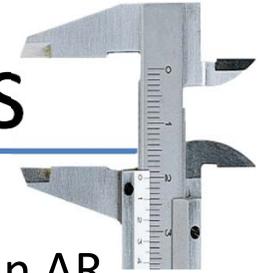
➤ The tracking module is the most important part of an AR system base for smartphone

➤ The tracking modules can be classified in:

✓ Marker vision-based tracking modules

✓ Markerless vision-based tracking modules

✓ Sensor-based tracking modules

✓ Hybrid tracking modules

Marker vision-based tracking modules (1/2)

➢ Picture/template marker AR systems:

✓ The module recognizes the object position by matching the pattern of the acquired image with the pre-stored template
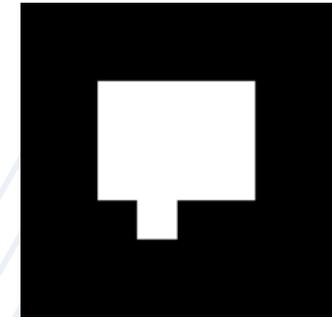
➢ ID-encoded AR systems:

✓ They are identified through decoding algorithm

✓ An ID identifies each marker

✓ Example: QR code

Marker vision-based tracking modules   (2/2)

Captured image from video camera

Binary image

Fiducial marker localization

Combined image

Measurements for AR systems; The tracking module
Markerless vision-based tracking modules (1/2)

➢ Markerless trackers are based on key points recognition

➢ They use natural features of the surrounding environment for identifying the position of real objects

Markerless vision-based tracking modules (2/2)

- ➤ The key points have the following features:
  - ✓ Not vary significantly under different lighting conditions
  - ✓ Robust against observation from different viewing angles
  - ✓ Their recognition should be fast as possible
- ➤ Key points:
  - ✓ Corner detection
  - ✓ Blob detection

Markerless vision-based tracking modules (2/2)

Corner detection

➢ Algorithms for searching points having maximum curvature

➢ Algorithms for searching the intersection points of edge segments

Blob detection

➢ A blob is a region of an image in which some properties are constant or vary within a prescribed range of values
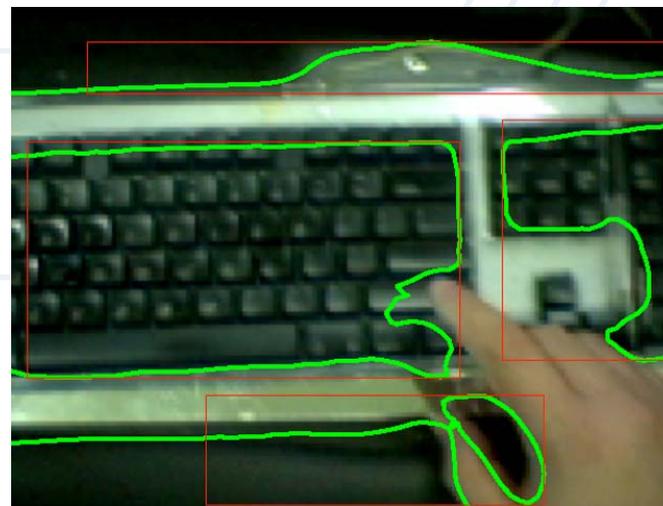
Example: Google Goggles

➢ Scan barcodes using Goggles to get product information

➢ Scan QR codes using Goggles to extract information

➢ Recognize famous landmarks

➢ Translate by taking a picture of foreign language text

➢ Scan text using Optical Character Recognition (OCR)

➢ Recognize paintings, books, DVDs, CDs, and just about any 2D image

➢ Find similar products
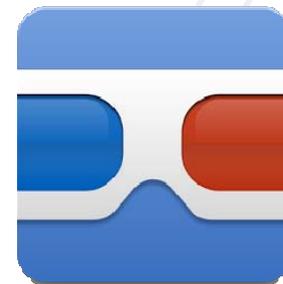
Sensor-based tracking modules

➢ Sensor-based tracking modules:

- ✓ Inertial sensors (IMU)
- ✓ GPS modules
- ✓ RFID modules
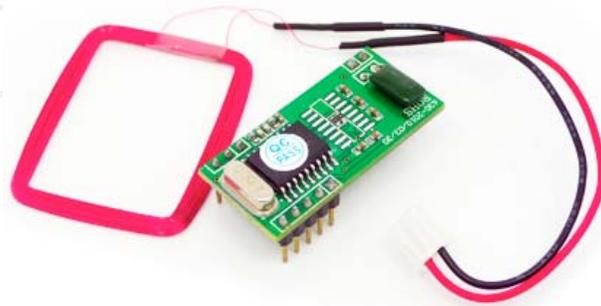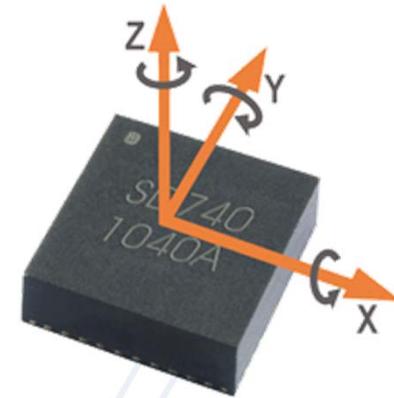
Sensor-based tracking modules

Inertial sensors (IMU)
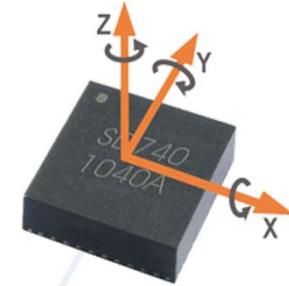
➤ The Inertial/Magnetic Measurement Unit is used in AR as tracking system for video camera

➤ Inertial/Magnetic Measurement Unit:

✓ 9-DOF: 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer

➤ In order to measure the angles of yaw, pitch and roll, a data fusion algorithm is used.

GPS modules

➢ The GPS receiver evaluates Times Of Arrival (TOA) of signals from each at least three satellites

➢ The internal clock of the GPS module is synchronized with the atomic clock placed on another satellite

➢ By knowing the speed of the electromagnetic wave, it is possible to localize the GPS module

➢ GPS modules are used for outdoor AR systems

Sensor-based tracking modules

RFID modules

RFID indoor positioning system

Wi-Fi

Server

Wi-Fi

Active RFID reader

Mobile phone

User AR system

RFID reader
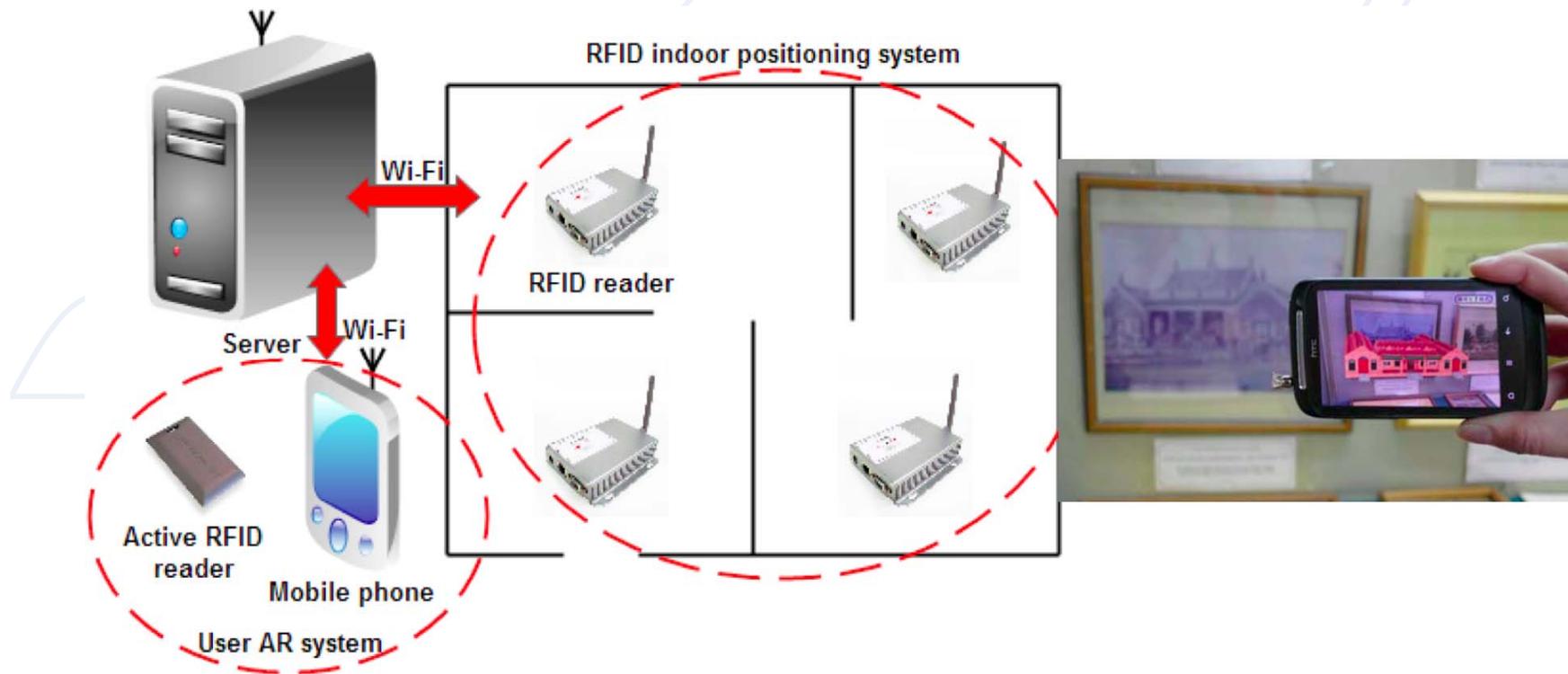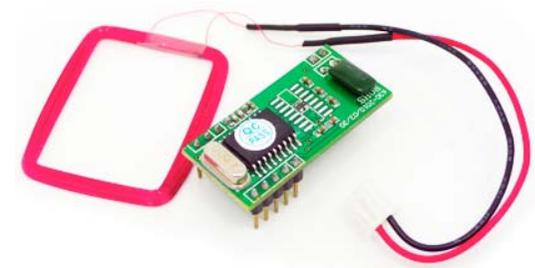
Tracking modules: errors
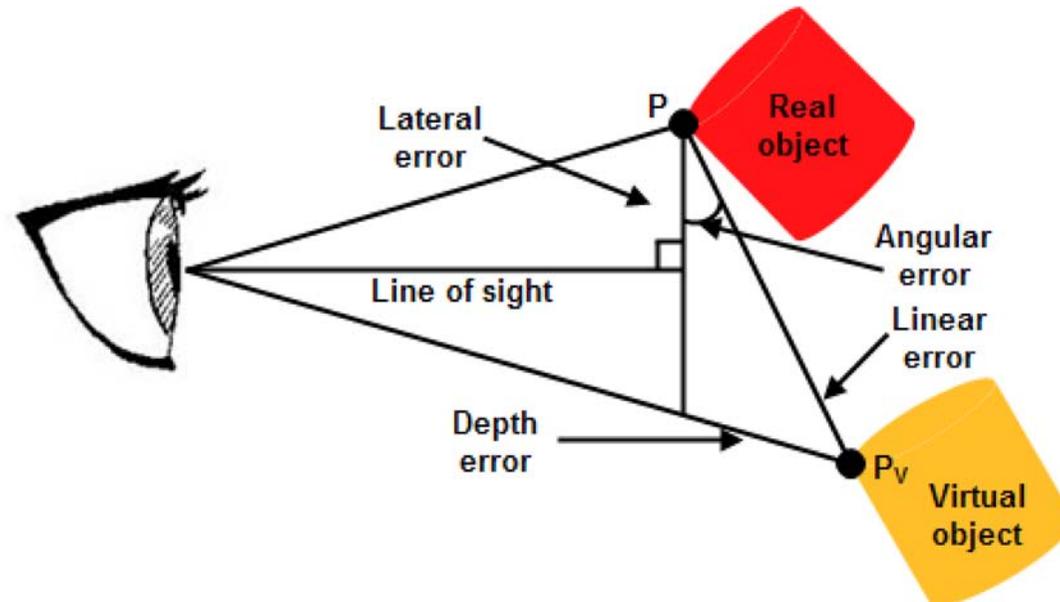
Registration errors: misalignment between real objects and virtual objects

Sources of Registration Errors
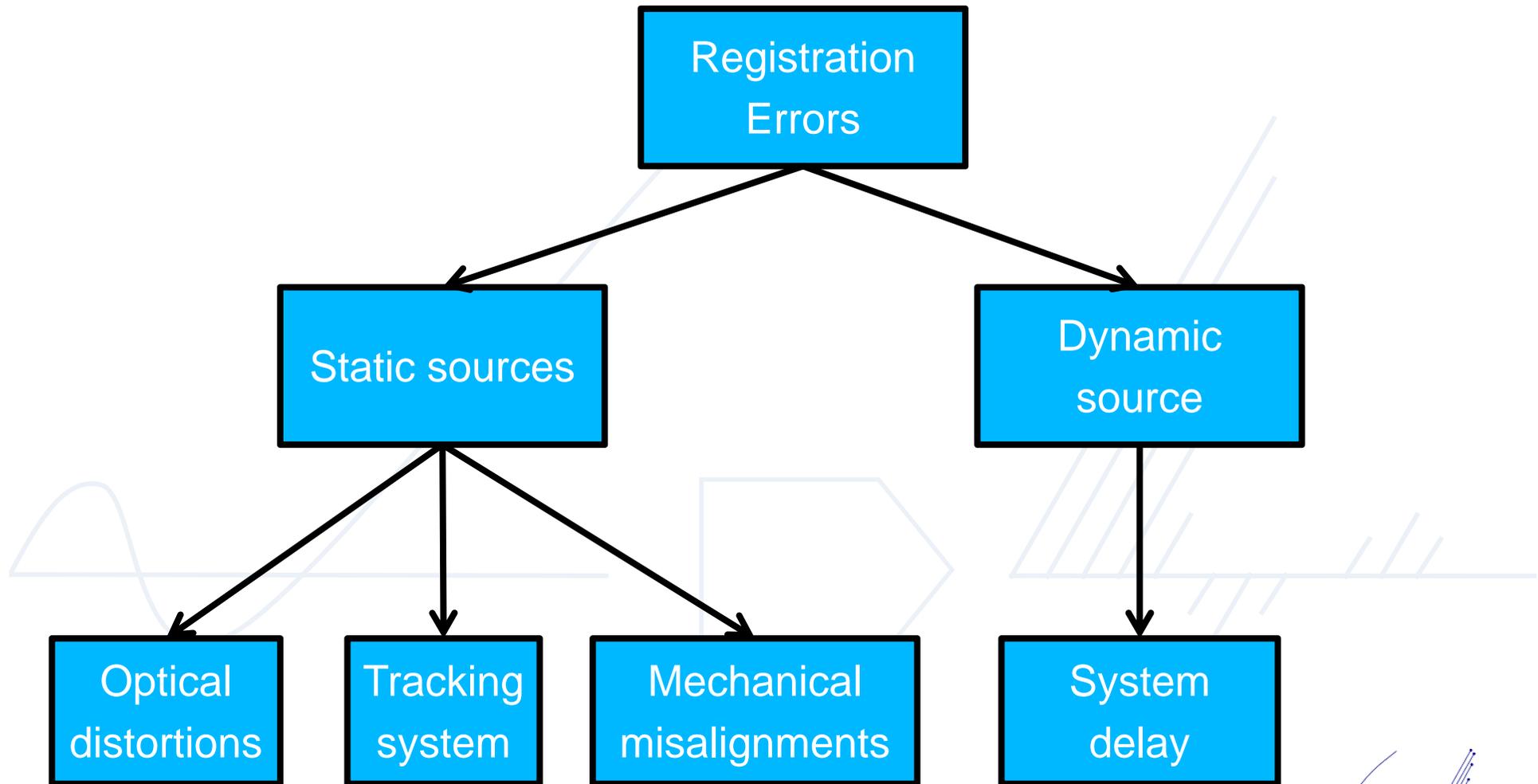
Tracking modules: a comparison

Tracking module	Accuracy	Time Latency
Sensor-based (IMU)	Low	Low
Marker-based	High	Low
Markerless-based	High	High

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The AR for measuring

- AR as user interface of measurement system

- The AR system communicates with a measurement system

- The AR system displays to the user the measurement data through text box, 3D graph and image models

Example (1)

Smartphone

Virtual Object

Real world

flex sensor

eGlove Circuit Module

eGlove

Battery
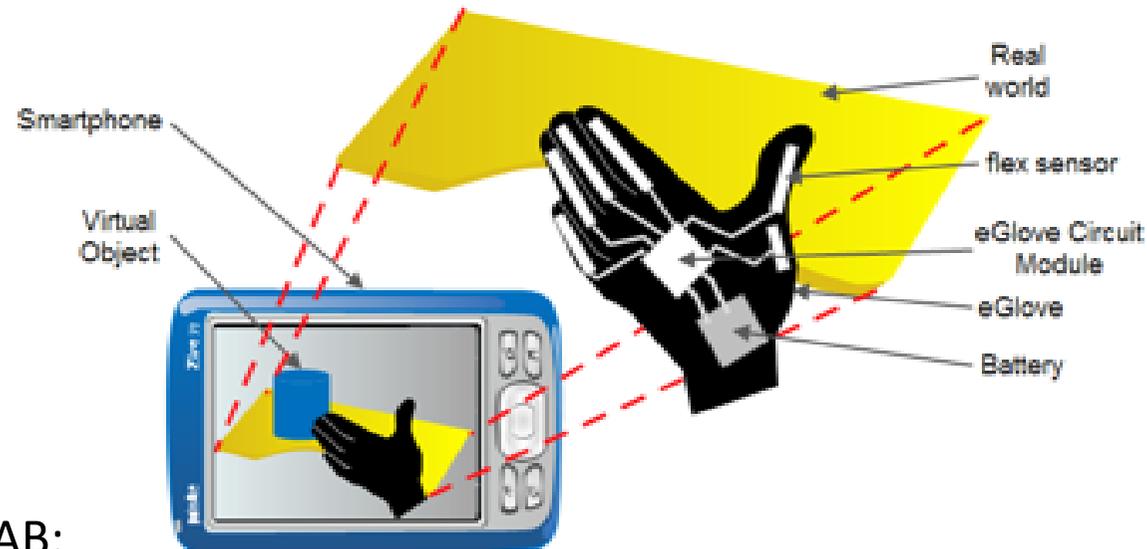
➢ Ubi-REHAB:

  ✓ eGlove detects the movements of a real hand through six bending sensors and accelerometers

  ✓ the eGlove sends to the smartphone the measured data via Bluetooth

  ✓ by using the measured data, the smartphone generates a virtual hand

  ✓ the smartphone overlays the real image captured by the video camera with a virtual hand and virtual objects

  ✓ By moving the hand, the user through the smartphone interacts with the virtual objects

  ✓ The user performs rehabilitation exercises

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Example (2)

Wall

Marker 1

Marker n

Wi-Fi

Server

Embedded plattform

Temperature sensor

Acoustic sensor

WSN node

Handheld AR device

WSN

A/D L.E.S.I.M.
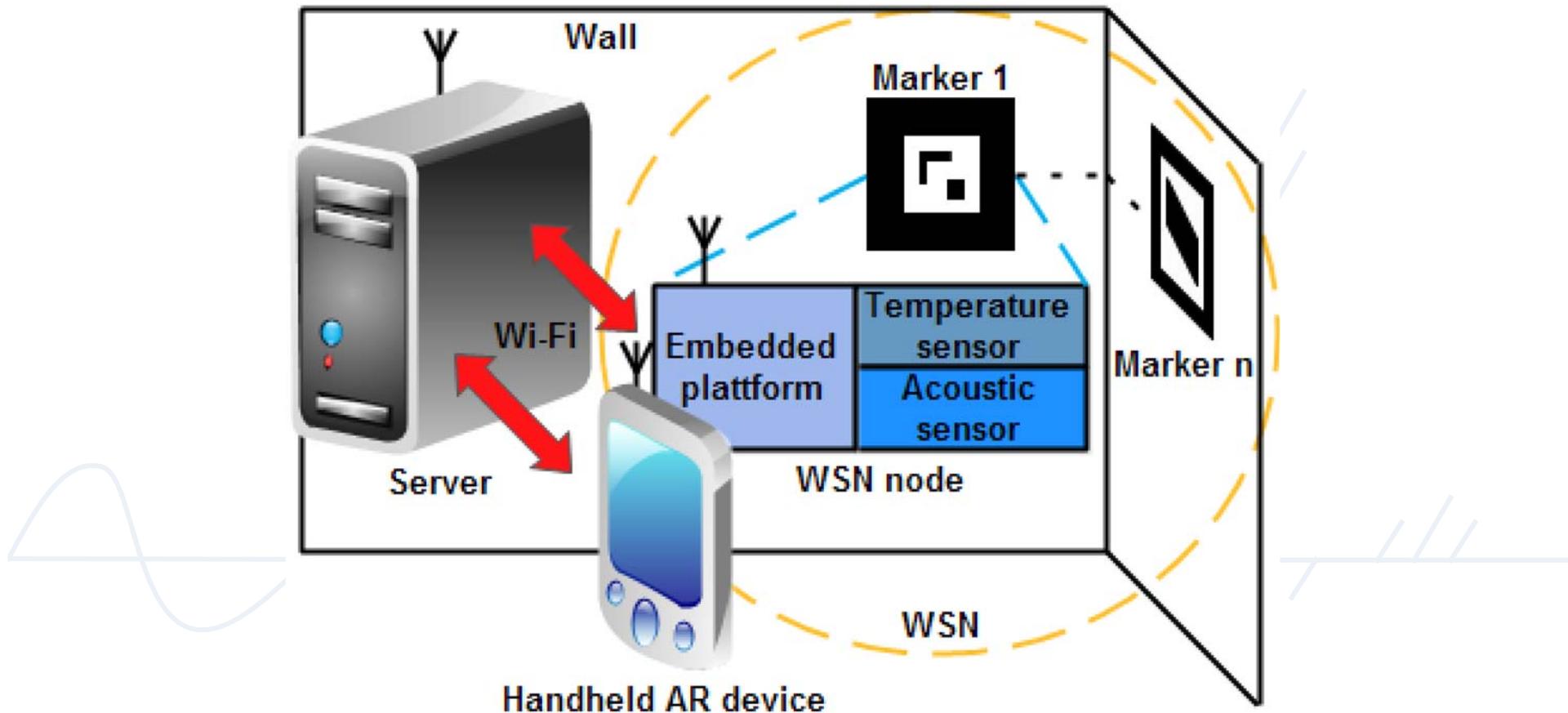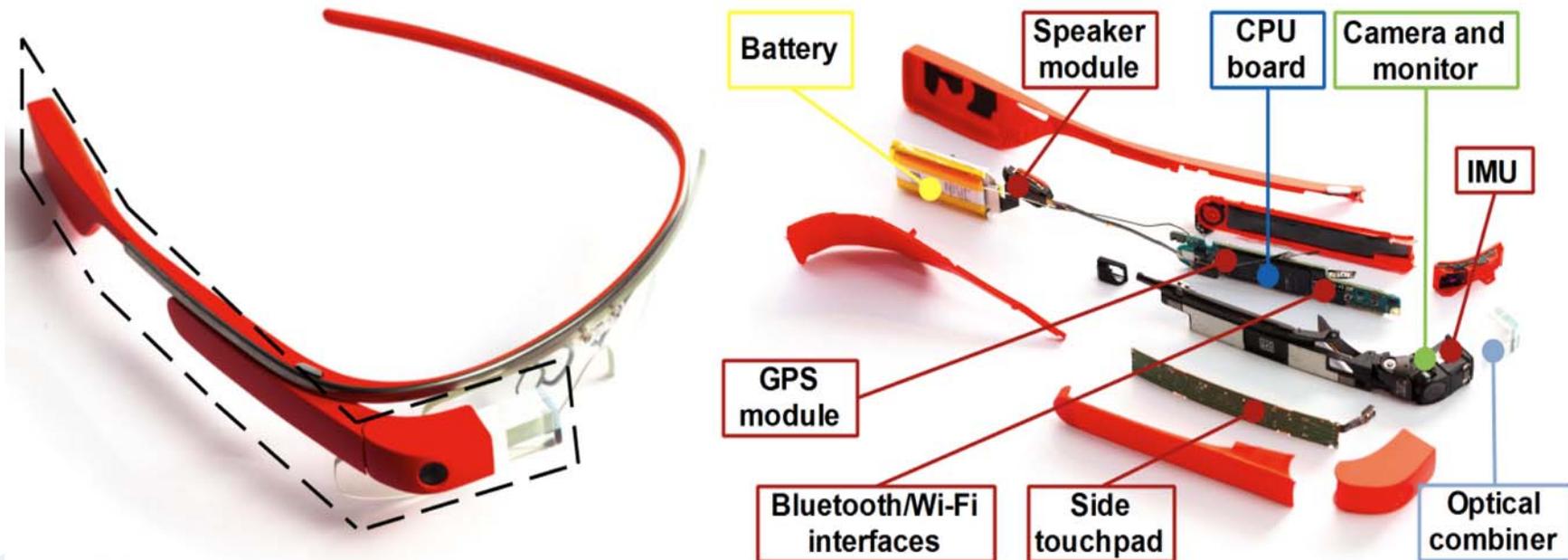
AR: future trends (1)

Google Glass: an optical see-through Head
Mounted Display (HMD)

AR: future trends (2)

➢ Designing of user interfaces that represent in a significant manner the measurement data

➢ Implementation of AR systems based on smartphone that can communicates with several measurement systems in a simple way (e.g. oscilloscope, multimeter, and Wireless Sensor Network, etc.)

➢ AR for implementing learning application on smartphone about measurements

References

➢ **State of the Art and Future Developments of Measurement Applications on Smartphones**, P.Daponte, L.De Vito, F.Picariello, M.Riccio, Measurement Journal, vol. 46, Issue 9, Nov. 2013, pp. 3291–3307.

➢ **State of the art and future developments of the Augmented Reality for Measurements applications**, P.Daponte, L.DeVito, F.Picariello, M.Riccio, under revision, Measurement Journal.

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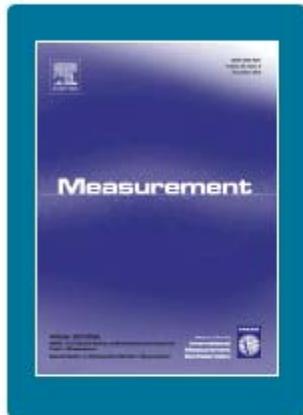
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State of the art and future developments of measurement applications on smartphones
November 2013
P. Daponte | L. De Vito | F. Picariello | M. Riccio

Abstract: The modern smartphones contain different sensor technologies, so they can be used as stand-alone measurement instruments on a wide range of application domains. The paper deals with a survey of measurement applications based on smartphones. In the first part, the evolution of mobile phone technologies, including the sensors and mobile networks developments, is presented. Then, in order to highlight the sensors and the communication capabilities, the architectural overview of the hardware and software technologies, which are available on latest series of smartphones, is reported and discussed. A review of measurements applications using the smart sensors and the communication interfaces available on smartphones, it is also presented. A classification of smartphone applications, which looks the smartphone as a handheld measurement instrument, is presented. In the last part, the integration of augmented reality to the measurement applications and new type of measurement systems, having a smartphone as processing support, is presented.

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Thank you for your attention!