Smartphones and Augmented Reality for Measurement Applications

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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.
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.
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
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.
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?
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.

For the everyday experience, a usable measurement system has the following features:
- non-invasive
- user friendly
- portable.
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.
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**: The most important part of the AP. It has the same capabilities as the processors in personal computers or laptops, and it is optimized for minimal power consumption.

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

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

- **Wireless Interface Modules (WIMs)**: are used for the wireless communication, for example Bluetooth, GSM and Wi-Fi.
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).
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 detect the sound intensity around you and provides you detailed information about the intensity changes.
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

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)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Description</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Mechanical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>Measurement range</td>
<td>User-selectable</td>
<td>±2.0</td>
<td></td>
<td></td>
<td>g</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±4.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>±8.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_o</td>
<td>Sensitivity 12bit</td>
<td>FS = ±2 g</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>mg/digit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS = ±4 g</td>
<td>1.8</td>
<td>2.0</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS = ±8.0 g</td>
<td>3.5</td>
<td>3.9</td>
<td>4.3</td>
<td></td>
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<tr>
<td>S_oTC</td>
<td>Sensitivity vs. temperature</td>
<td>FS = ±2 g</td>
<td></td>
<td>±0.01</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td></td>
<td><strong>Electrical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_dd</td>
<td>Supply voltage</td>
<td></td>
<td>2.16</td>
<td>2.50</td>
<td>3.60</td>
<td>V</td>
</tr>
<tr>
<td>I_dd</td>
<td>Supply current</td>
<td>Active mode</td>
<td></td>
<td>250</td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>I_ddSL</td>
<td></td>
<td>Sleep mode</td>
<td></td>
<td>10</td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>I_ddPdn</td>
<td></td>
<td>Power-down mode</td>
<td></td>
<td>5</td>
<td></td>
<td>μA</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>Symbol</th>
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<th>Max.</th>
<th>Unit</th>
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<td></td>
<td><strong>Mechanical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>Measurement range</td>
<td>User-selectable</td>
<td>±250</td>
<td>±500</td>
<td>±2000</td>
<td>°/s</td>
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<tr>
<td></td>
<td>S₀</td>
<td>Sensitivity</td>
<td>FS=250 °/s</td>
<td>8.75</td>
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<td>m°/s/digit</td>
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<tr>
<td></td>
<td></td>
<td>FS=500 °/s</td>
<td>17.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS=2000 °/s</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>S₀Dr</td>
<td>Sensitivity vs. temperature</td>
<td>From -40 °C to +85 °C</td>
<td>±2</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>NL</td>
<td>Non linearity</td>
<td></td>
<td>0.2</td>
<td></td>
<td></td>
<td>% FS</td>
</tr>
<tr>
<td></td>
<td><strong>Electrical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vdd</td>
<td>Supply voltage</td>
<td></td>
<td>2.4</td>
<td>3.0</td>
<td>3.6</td>
<td>V</td>
</tr>
<tr>
<td>Idd</td>
<td>Supply current</td>
<td>Active mode</td>
<td>6.1</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>IddSL</td>
<td></td>
<td>Sleep mode</td>
<td>1.5</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>IddPdn</td>
<td></td>
<td>Power-Down mode</td>
<td>5</td>
<td></td>
<td></td>
<td>μA</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Example</th>
<th>Field strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth’s magnetic field on the equator (0° latitude)</td>
<td>31 µT</td>
</tr>
<tr>
<td>Typical fridge magnet</td>
<td>5 mT</td>
</tr>
<tr>
<td>Strong neodymium magnet</td>
<td>1.25 T</td>
</tr>
<tr>
<td>MRI (Magnetic resonance imaging) system</td>
<td>1.5 T – 3 T</td>
</tr>
</tbody>
</table>

- Applications
  - Compass, of course – rotate maps/interfaces/graphics according to bearing
  - Detect magnets, force fields
Sensor Data Flow

Physical
- Ambient light
- Barometer
- Thermometer
- 3D Accelerometer
- 3D Gyroscope
- 3D Magnetometer

Firmware Processor
- Pass-Through and Calibration

Sensor Fusion

User Sensor
- Ambient light
- Barometer
- Thermometer
- Accelerometer
- Gyrometer
- Compass
- Inclinometer
- Orientation
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.
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.
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.

Embedded SPMI

The smartphone acts as an **Embedded SmartPhone based Measurement Instrument (ESPMI)** if it receives the measured value directly from its embedded sensors.
The smartphone acts as a SmartPhone based Measurement Instrument Interface (SPMI) II if it receives from an external measurement instrument the measured value and shows it to the user.
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 communicate with external devices via wireless.
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
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

ESPMI – Recognition Of Aggressive Driving

- This system recognizes the driving style in order to detect potential dangerous situations.
- By using the smartphone, one can 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.

Embedded SmartPhone based Measurement Instrument (ESPMI)

Outside oriented applications

Examples
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 49\(\mu\)T (microtesla) or 490mG (milligauss); 1\(\mu\)T = 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/
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.
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
- Electrodes
- Temperature Probe
- ECG, Respiration, GSR, 3-axis accelerometer, Ambient and skin temperature
- Alcohol, PPG sensor in arm band
SmartPhone based Measurement Instrument Interface (SPMII)

Outside oriented applications

Examples
SPMII – Temperature & Humidity Sensor

- iCelsius RH
  - Temperature range
    -40° to +120°C
  - Accuracy ±0.5 °C, 0-100% RH+2%
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 troubleshooting.
SPMII – Sensordrone

13 different sensors: from gas oxidization to color intensity measurement

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

http://www.sensorex.com/
SPMII – Chemical Sensors (1)

- Carbon monoxide
- Chlorine
- Ammonia
- Methane
- Blood sugar
- Etc.

Postage-sized chip with 32 nanosensor bars
It can detect killer gases 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.

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
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.

Conventional solution

<table>
<thead>
<tr>
<th>Continuous Operation</th>
<th>Host CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>Pressure sensor</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>Ambient Light</td>
</tr>
<tr>
<td>Geomagnetic sensor</td>
<td>Proximity sensor</td>
</tr>
<tr>
<td>Temperature sensor</td>
<td>UV sensor</td>
</tr>
<tr>
<td>Humidity sensor</td>
<td>X-ray sensor</td>
</tr>
<tr>
<td>Infrared sensor</td>
<td>Sensor</td>
</tr>
</tbody>
</table>

Hub microcontroller solution

<table>
<thead>
<tr>
<th>Standby</th>
<th>Control</th>
<th>Continuous Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host CPU</td>
<td>Low power micro processor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Data Logging</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Precalculation for sensor APs</td>
<td></td>
</tr>
</tbody>
</table>

| Accelerometer | Pressure sensor |
| Gyroscope     | Ambient Light |
| Geomagnetic sensor | Proximity sensor |
| Temperature sensor | UV sensor |
| Humidity sensor | X-ray sensor |
| Infrared sensor | Sensor |

Independent sensor control without host CPU
Sensor Hub Microcontroller for Smartphones (2)

Conventional solution

Continuous Operation
- Accelerometer
- Gyroscope
- Geomagnetic sensor
- Temperature sensor
- Humidity sensor
- Infrared sensor
- Pressure sensor
- Ambient Light
- Proximity sensor
- UV sensor
- X-ray sensor
- Sensor

Standby
- Host CPU

Control
- Low power micro processor
  - Data Logging
  - Precalculation for sensor APs

Continuous Operation
- Accelerometer
- Gyroscope
- Geomagnetic sensor
- Temperature sensor
- Humidity sensor
- Infrared sensor
- Pressure sensor
- Ambient Light
- Proximity sensor
- UV sensor
- X-ray sensor
- Sensor

Electric Current
- Host processor operation
  - Sensor access
- Host processor standby state
Sensor Hub Microcontroller for Smartphones (3)

Conventional solution

Hub microcontroller solution

Logging flexible due to pre-calculation by sensor output
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.
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.
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


- 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


- Within-day reliability of shoulder range of motion measurement with a smartphone, Manual Therapy, vol.17, No. 4, August, 2012, pp. 298-304
What is Augmented 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
Benford's AR definition: “AR combines a local transportation level with virtual environment”
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
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
Measurements for AR systems; The tracking module

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
Measurements for AR systems; The tracking module

Marker vision-based tracking modules (2/2)
Markerless trackers are based on key points recognition

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

- Algorithms for searching points having maximum curvature
- Algorithms for searching the intersection points of edge segments

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

**Sensor-based tracking modules**

- Inertial sensors (IMU)
- GPS modules
- RFID 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.
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.
Measurements for AR systems; The tracking module

Sensor-based tracking modules

RFID modules
Tracking modules: errors

Registration errors: misalignment between real objects and virtual objects
Sources of Registration Errors

Registration Errors

Static sources
- Optical distortions
- Tracking system
- Mechanical misalignments

Dynamic source
- System delay
## Tracking modules: a comparison

<table>
<thead>
<tr>
<th>Tracking module</th>
<th>Accuracy</th>
<th>Time Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor-based (IMU)</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Marker-based</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Markerless-based</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
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)

- **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.
Example (2)
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

November 2013
F. 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.
Thank you for your attention!