Embedded System Design & Applications Laboratory

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Presentation Title

Name & Affiliation

https://www.esdalab.ece.uop.gr

Outline

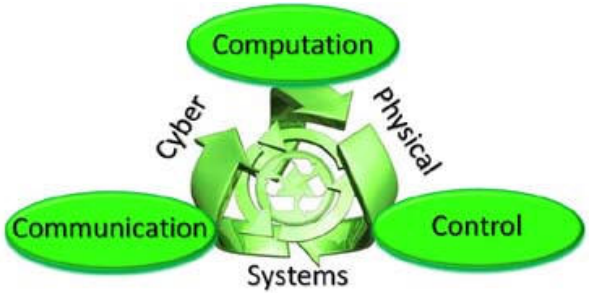
- What are Cyber Physical Systems?
- Challenges of CPS
- CPS vs Embedded Systems
- Characteristics of CPS
- CPS perspectives
- Why are CPS significant?
- Concept map of CPS
- Examples
- Case study: ARMOR CPS
- ARMOR Demonstrators

What are Cyber Physical Systems?

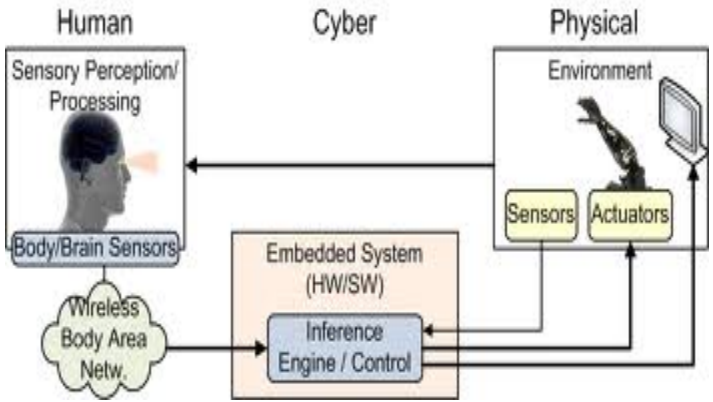
- Cyber Physical Systems are an exciting emerging research area that has drawn the attention of many researchers
- Although the question of “What is a CPS?” remains open, widely recognized and accepted
- The term Cyber-Physical Systems (CPS) refers to the integration of computation with physical processes - Coined in 2006 by Helen Gill (US National Science Foundation)
- A CPS can be further described *as any physical or engineered system whose operations are monitored, coordinated, controlled and integrated by one or more computing and communication cores*

What are Cyber Physical Systems?

- **Cyber** Computation, Communication and Control
- **Physical** Natural and human-made systems governed by the laws of physics in continuous time
- **Cyber Physical Systems** Systems in which the cyber and physical systems are integrated at all scales and levels



What are Cyber Physical Systems?



- The term Cyber Physical Systems (CPS) refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans **through many new modalities**
- The ability to interact with the physical world through computation, communication, and control **is a key enabler for future technology developments**

What are Cyber Physical Systems?

From an engineering point of view, a CPS can be decomposed in:

- **Embedded systems,** using sensors for monitoring and collecting data from one ore more physical processes, like
  - ✓ steering of a vehicle
  - ✓ human health functions
  - ✓ energy consumption
- **Software applications** that can directly interact with events in the physical world, e.g.
  - ✓ in autonomous driving
  - ✓ intelligent manufacturing
  - ✓ smart health
  - ✓ energy systems

What are Cyber Physical Systems?

- Applications of CPS arguably have the potential to outweigh the 20th century IT revolution
- In many daily activities we rely on CPS like
  - ✓Medical devices and systems
  - ✓Assisted living
  - ✓Traffic control and safety
  - ✓Advanced automotive system
  - ✓Energy conservation
- The areas of applications of CPS include:

✓Environmental control
✓Critical infrastructure control
✓Instrumentation
✓Robotics (telemedicine)
✓defense systems
✓smart structures

Challenges of CPS

- The economic and societal potential of such systems is vastly greater than what has been realized, and major investments are being made worldwide to develop the technology
- There are considerable challenges, particularly because the physical components of such systems introduce **safety** and **reliability** requirements qualitatively different from those in general purpose computing

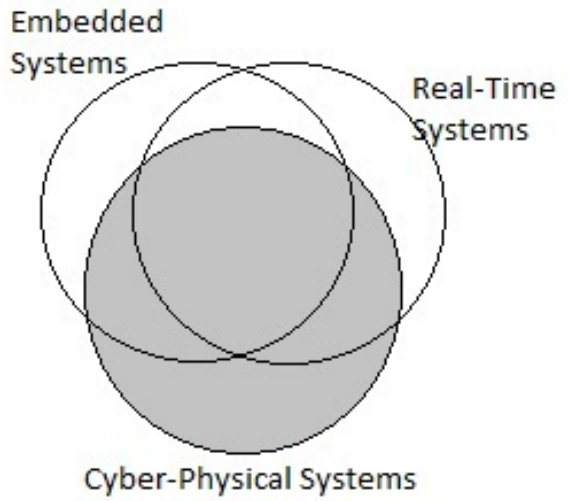
CPS vs Embedded Systems

CPS development is led by the confluence of

- Embedded systems
- Real-time systems
- Distributed sensor systems and controls

In conjunction with the availability of

- Increasingly low-cost
- Small-size
- Low-power, high-capability sensors and computing devices



CPS vs Embedded Systems

The embedded systems problem

- Embedded software is software on small computers
- The technical problem is one of optimization (coping with limited resources)

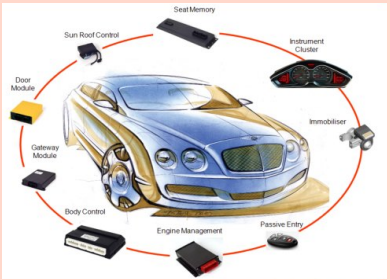
The CPS problem

- Computation and networking integrated with physical processes
- The technical problem is managing time and concurrency in networked computational systems

Characteristics of CPS

- Input and possible feedback from the physical environment
- Distributed management and control
- Real-time performance requirements
- Wide geographic distribution, with components in locations that lack physical security
- Harmonized and seamless operation and coexistence of diverse systems

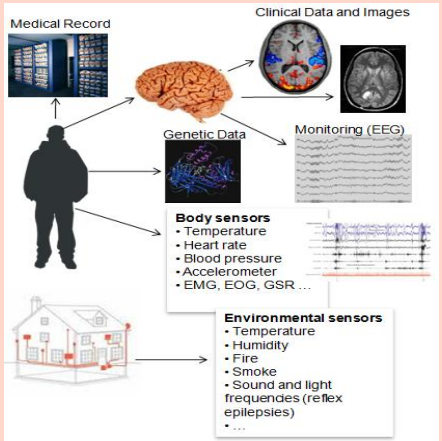
CPS Perspectives

Sector	Opportunities	
Transportation	✓ Aircrafts that fly faster with fewer energy/fuel consumption ✓ Air traffic control systems that make more efficient use of air space ✓ Automobiles/trains that are more capable, safer and energy aware ✓ More efficient fleet management	 

CPS Perspectives

Sector	Opportunities	
Defense	✓ More capable defense systems ✓ Defense systems that make better use of network fleets of autonomous vehicles	
Energy and industrial automation	✓ New and renewable energy sources ✓ Homes, offices, buildings and vehicles that are more energy efficient and cheaper to operate	

CPS Perspectives

Sector	Opportunities	
Medical systems	✓ Better monitoring of patients ✓ Reduced treatment cost and hospitalization time ✓ Better prognosis ✓ Personalized treatment ✓ Patient's life quality improvement	

Why are CPS significant?

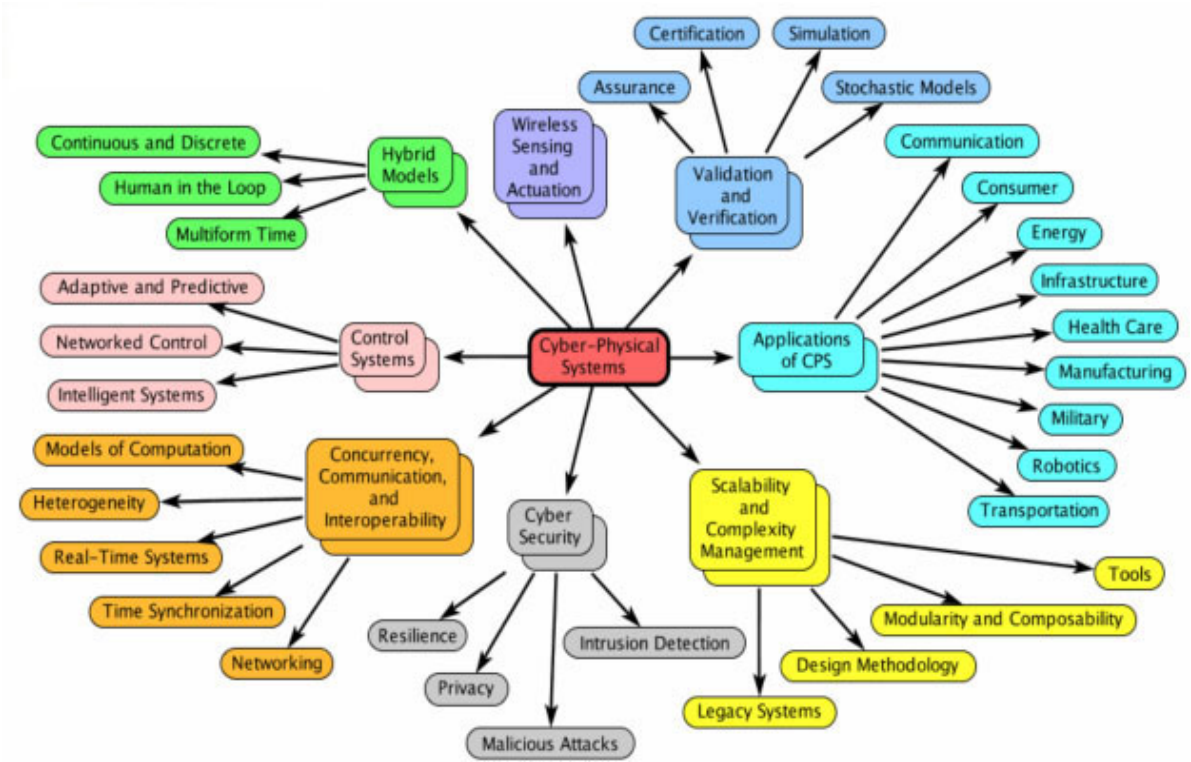
- Building systems that integrate computational and physical objects requires new systems science foundations
- The Expected share of value of embedded computing components in the next five years:
  - ✓ Automotive and airspace systems 30-40%
  - ✓ Health/Medical equipment 33%
  - ✓ Industrial automation 22%
  - ✓ Telecommunications 37%
  - ✓ Intelligent Homes 41%
- CPS are the basic engine of innovation for a broad range of industrial sectors

Why are CPS significant?

CPS provide several advantages including:

- Quick response times
- Increased levels of precision
- Improved efficiency and resource utilization
- The ability to work in dangerous or previously inaccessible environments
- Large-scale, coordinated distributed systems
- Augmentation of human capabilities

Concept map of CPS



Examples

Automotive Telematics

- Combine the power of computers and computer systems with remote communications technologies (such as GPS, wireless, cellular, etc)
- **Goal:** to obtain information about remote automotive vehicles

Examples

Health care & Medicine

- **National Health Information Network**

✓ Electronic Patient Record

✓ Medical records at any point of service

✓ Hospital, Operating Rooms (OR), Intensive Care Units (ICU)

Examples

Health care & Medicine

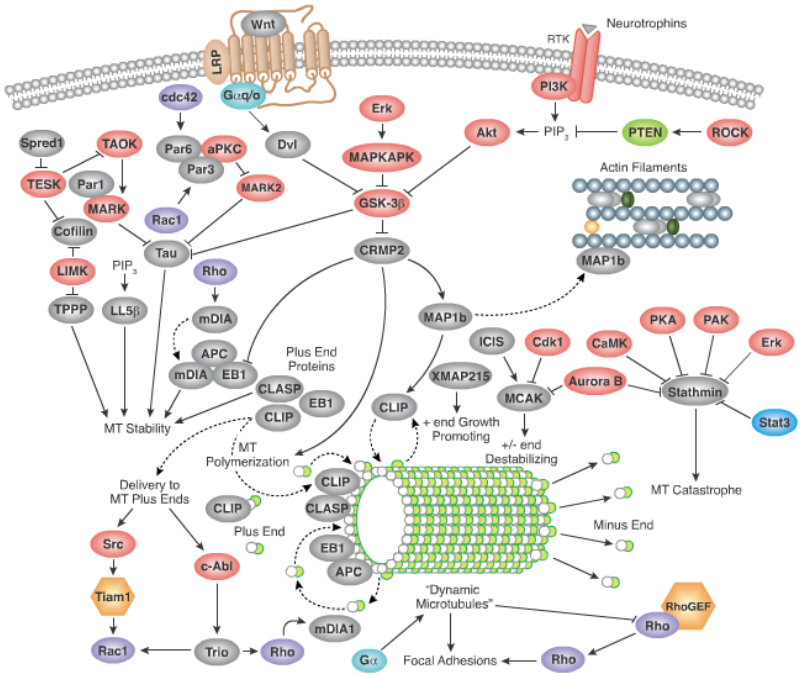
- **Home care: Monitoring and Control**
  - ✓ Pulse oximeters (oxygen saturation)
  - ✓ Blood
  - ✓ Glucose monitors
  - ✓ Infusion pumps (insulin)
  - ✓ Accelerometers (falling, immobility)
  - ✓ Wearable networks

Examples

Health care & Medicine

- **Operating Room of the Future**
  - ✓ Closed loop monitoring and control
  - ✓ Multiple treatment stations
  - ✓ Plug and play devices
  - ✓ Robotic microsurgery
  - ✓ System coordination

Examples



Health care & Medicine

- **Bioinformatics**
  - ✓ Gene
  - ✓ Protein expression
  - ✓ Systems biology
  - ✓ Disease dynamics
  - ✓ Control mechanisms
  - ✓ Personalized medicine

Examples

- **Health care & Medicine: The vision**

Case Study: ARMOR CPS

What is ARMOR CPS?

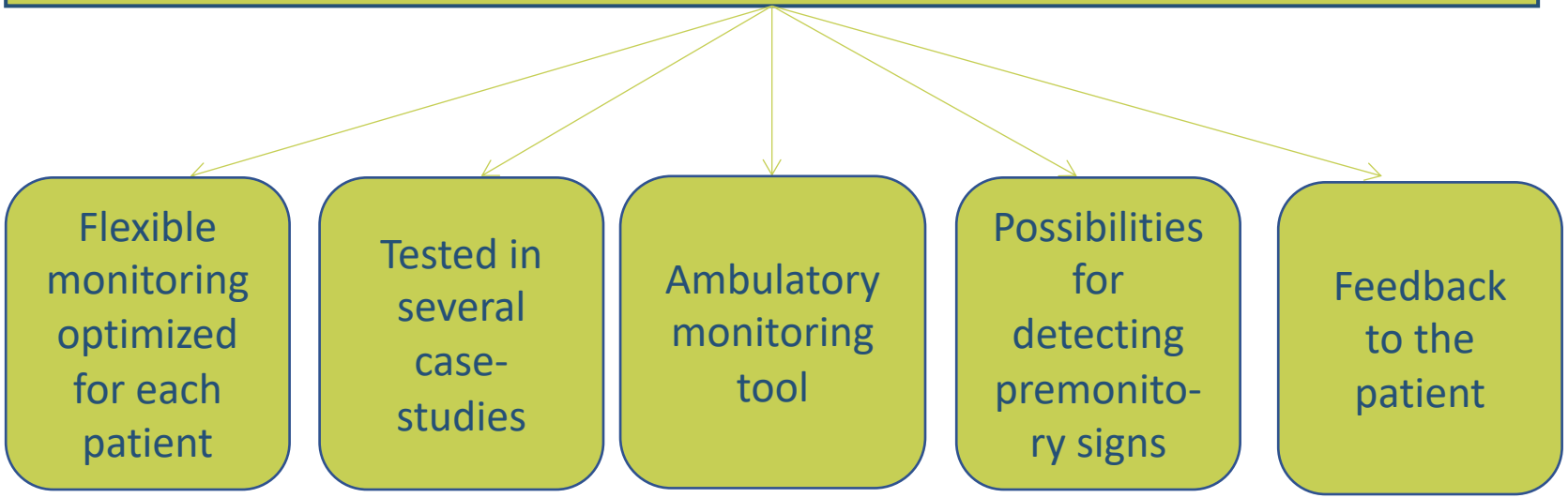
ARMOR is an **A**dvanced multi-pa**R**ametric **M**onitoring and analysis for diagnosis and **O**ptimal management of epilepsy and **R**elated brain disorders

Why is it important?

Epilepsy is the commonest serious brain disorder, affecting up to 1% of the population worldwide

Case Study: ARMOR CPS

ARMOR will design a more holistic, personalized, medically efficient and economical monitoring system for people with epilepsy.



Case Study: ARMOR CPS

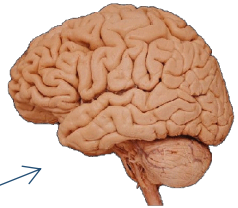
Scenarios

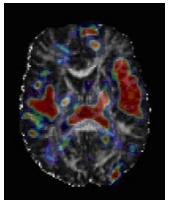
Offline						Online
SCENARIO 1	**SCENARIO2**	**SCENARIO3**	**SCENARIO5**	**SCENARIO6**	**SCENARIO7**	**SCENARIO 4**
Epilepsy or non-epileptic paroxysmal events (NEPE)	Delineation of the clinical EEG expression of different types of epilepsy	Follow Up – Medication evaluation	Research on local signs of idiopathic generalized epilepsy	Pre-surgical evaluation	Nocturnal Seizure	Protection from seizures

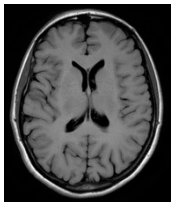
Case Study: ARMOR CPS

The Global Picture

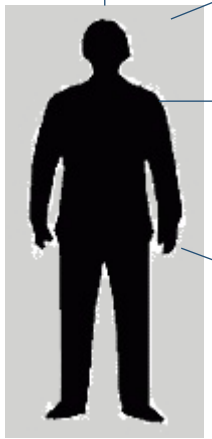
Medical Record



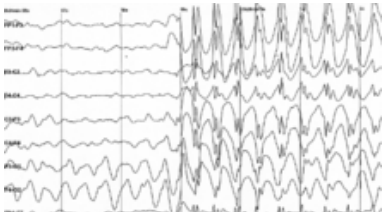




Clinical Data and Images



Genetic Data



Monitoring (EEG)

Body Sensors:

- Temperature
- Blood preasure
- EMG, EOG, GSR…
- Heart rate
- Accelerometer

\+ **Environmental Sensors**

Case Study: ARMOR CPS

ARMOR Sensors

- EEG-Sensor/EOG-Sensor
  - ✓ Electroencephalography
- ECG Sensor
  - ✓ Electrocardiogram
- Activity Sensor
  - ✓ 3 Dimensional acceleration sensors
- GSR Sensor
  - ✓ Galvanic Skin Response
- SPO2-Sensor
  - ✓ Saturation of peripheral oxygen
- Respiration
- EMG-Sensor
  - ✓ Electrical activity produced by skeletal muscles
- Context, environmental signals
  - ✓ Light and sound

ARMOR Sensors - Technical capabilities

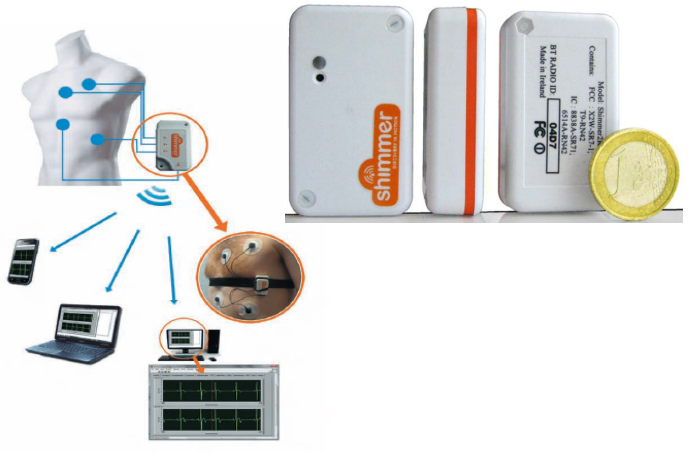
- ekgMove (Karlsruhe Institute of Technology)
- Applications
  - ✓ Measurements of ECG, Activity, Steps, Postures Energy expenditure
- Raw measurements
  - ✓ ECG, 12 bit resolution, up 1024 Hz
  - ✓ 3-axial acceleration sensor, 4mg resolution, up to 64 Hz
  - ✓ Air pressure sensor 0.03 hPa (hectopascal - 1 hPa = 100 Pa) and resolution 1 Hz
- Battery lifetime
  - ✓ Bluetooth inactive → 2 days
  - ✓ Bluetooth active → 4 hours
- Storage capacity
  - ✓ 2 Gbytes

Case Study: ARMOR CPS

Beyond ARMOR Sensors

- Shimmer Sensors (Commercial)
- Applications
  - ✓ Healthcare, Ambient Sensing Solutions
  - ✓ Remote Patient Monitoring Assistive Technology (Sports, Science + Athlete Development etc)
- Ideal for research
  - Highly Configurable, Open source, No proprietary software

- Wide range of Sensor Support
  - ECG, EMG, GSR, GPS, Accelerometer, Temperature



Case Study: ARMOR CPS

Conceptual Architecture

Data Acquisition from Multi-parametric Sensors

Data Storage
- Preprocessing sensor data
- Data and dimensionality reduction

Data Fusion
- Keep sensor data appropriate for alerting

Streaming Data

Adjustment real time prediction model parameters

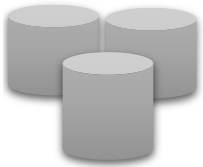
Store results

Local Site

REAL TIME ANALYSIS
- Real time decision support tool for advising the patient producing warnings, handling emergency situations
- Data mining
- Personalised analysis based on patient's profile

Health Center

- Remote health monitoring system
- Medical Expertise
- **Medical Database**: Sensor measurement, patient profile and current status, already available related data from previous studies



DB

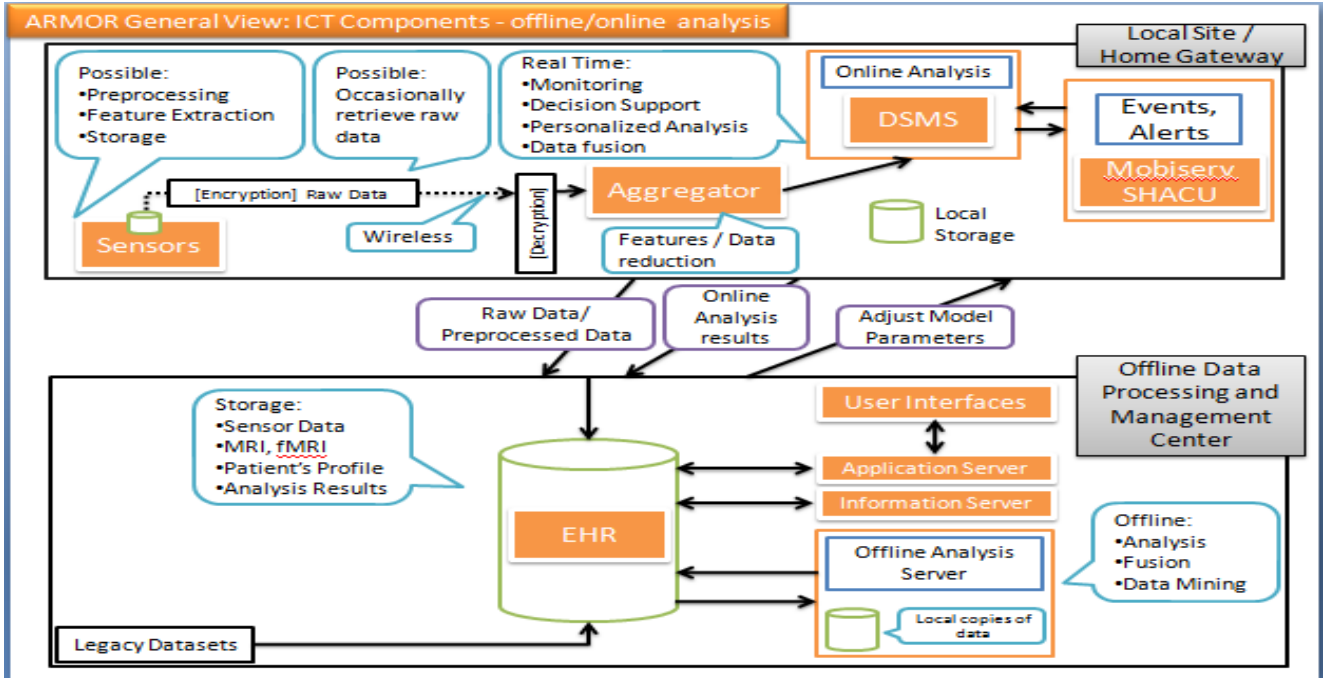
Data Fusion
- Use stored data in large scale data analysis

- Communication with DB
- Modify patient's current status
- Store lab test's results

OFFLINE ANALYSIS
- Analysis of multipara-metric sensor data in health centers
- Data fusion and correla-tion with imaging data, genetic data, etc.
- Lab tests to advance clinical knowledge in neu-roscience and epileptology

Case Study: ARMOR CPS

Physical Architecture



Case Study: ARMOR CPS

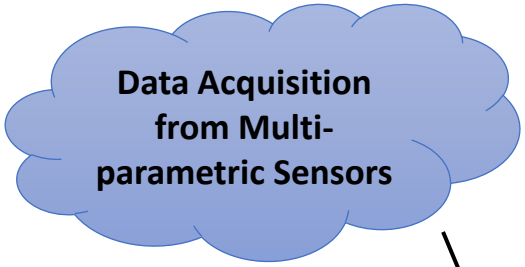
Architecture challenges

- The Wireless Sensor Network (WSN) posses some of the most challenging issues in the end-to-end architecture
  - ✓ High number of different modalities must be acquired and efficiently transmitted to the aggregation point (i.e. home gateway for ARMOR)
    - EEG, ECG, GSR, Accelerometer, Temperature and many more
  - ✓ All different required sensors result into a excessive amount data that must be conveyed over a limited bandwidth wireless channel
    - Each measurement results typically into a 16bit number
    - Sampling rate may vary from a few tenths of Hz up to 2,5KHz for high precision EEG

Architecture challenges

- ✓ Storing data to the sensors is also problematic due to the limited amount of memory provided by typical sensors as opposed the mount of data already mentioned
  - Sensors are expected to operate independently for many hours and even days
- ✓ Time constrained communication also comprise a difficult requirement to meet
  - Critical data must be received by the doctors, caregivers or even automated data processing system inside specific time windows otherwise response could be futile
  - Parallel observation or processing of data from different modalities require strict synchronization and minimum inter-signal time differences

Case Study: ARMOR CPS



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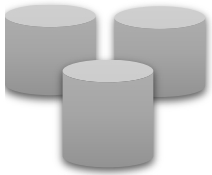

- Communication with DB
- Modify patient's current status
- Store lab test's results

- Remote health monitoring system
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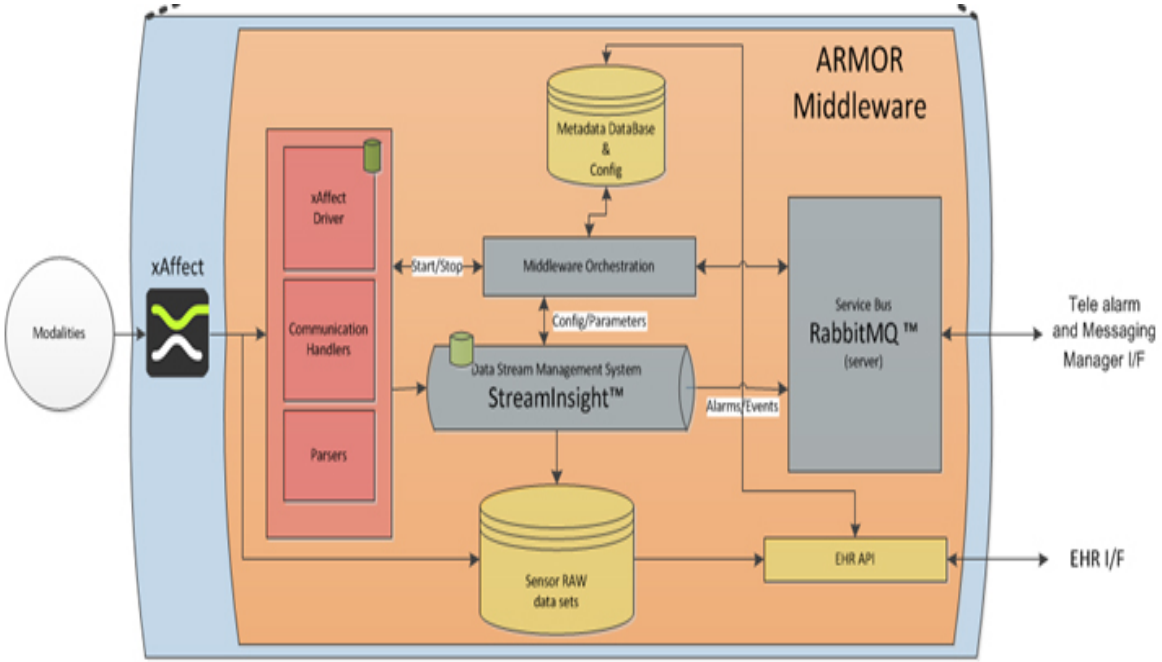
Case Study: ARMOR CPS

Architecture challenges

- ✓ Node lifetime represent probably the most challenging aspect of WSN in demanding medical applications
  - Nodes using typically very small batteries are expected to operate unattended from nay hours performing quite demining communicational and processing tasks
- ✓ Security provision also represent an absolute must in such scenarios
  - Achieving, however, high level of data privacy, authentication and authorization while offering efficient communication performance and extended lifetime requires significant advancements in various collaborating research areas

Case Study: ARMOR CPS

Software (Middleware)

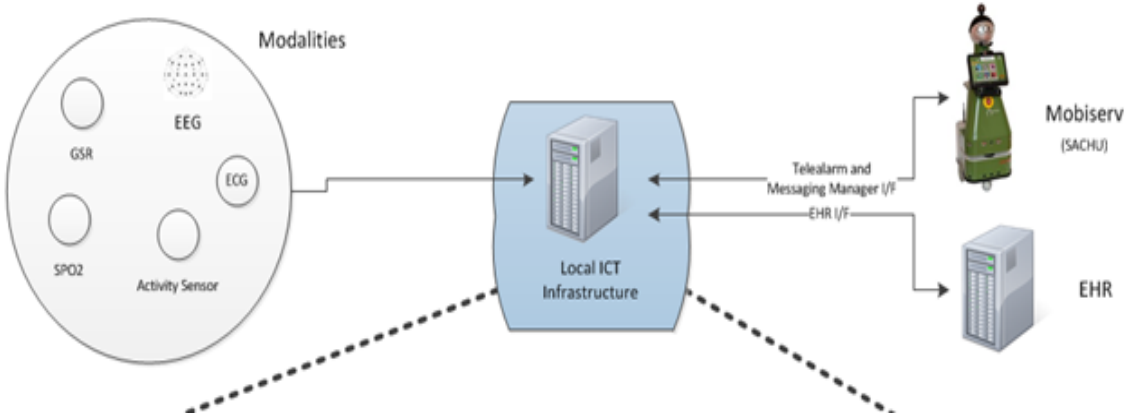


Software (Communication)

- Communication related advancements are also required
- WSN Communication
  - ✓ State-of-the-art Encryption algorithms must be utilized to assure security provision
  - ✓ Both Software and Hardware solutions are considered
  - ✓ Data compression algorithms are studied, evaluated and extended so as
    1. Minimize the required data transmission saving energy
    2. Enabling storage of high mount of data
- Back end communication (Home Gateway – Doctors/Hospitals/etc)
  - ✓ Efficient communication protocol to transfer high amount of data
  - ✓ Security provision

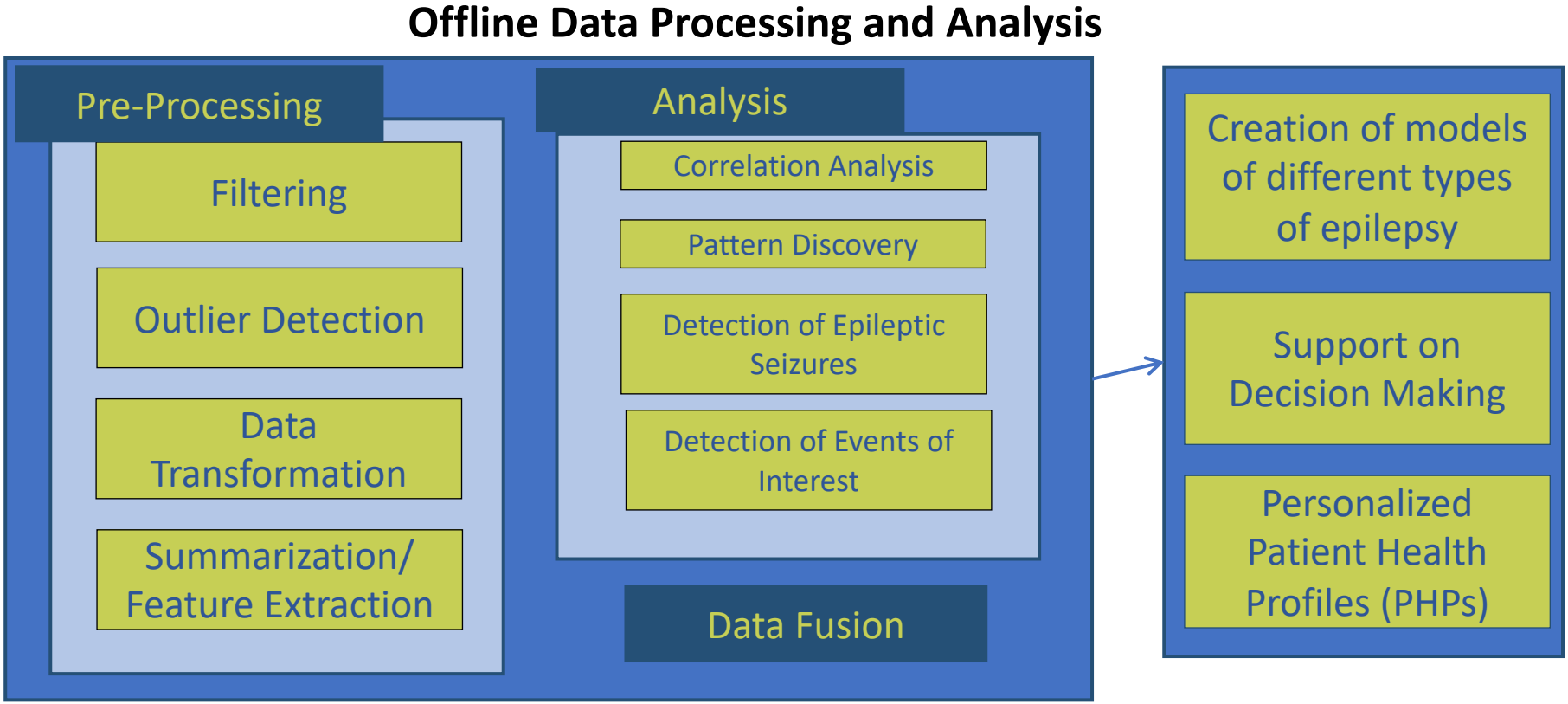
Case Study: ARMOR CPS

Software (Communication)



ICT infrastructure developed by ARMOR

Case Study: ARMOR CPS



Online Data Processing and Analysis

Online Analysis will incorporate all necessary processing techniques adopted to the streaming nature of the data, in order to perform real-time:

- Detection of Seizures
- Detection of abnormal values (patient-specific) from several modalities like
  - ✓Excessive tachycardia
    - Oxygen level excursions
  - ✓Other possible emergency situations

Online Processing involves tasks such as:

- Preprocessing
- Data Fusion
- Decision making

which will be performed with respect to processing time and memory constraints.

Online analysis will involve results from offline analysis in order to adjust parameters according to each patient's personal profile

Minimal Data Requirements (e.g. number of sensors) will be incorporated with respect to the medical expectations and the desired levels of accuracy

Case Study: ARMOR CPS

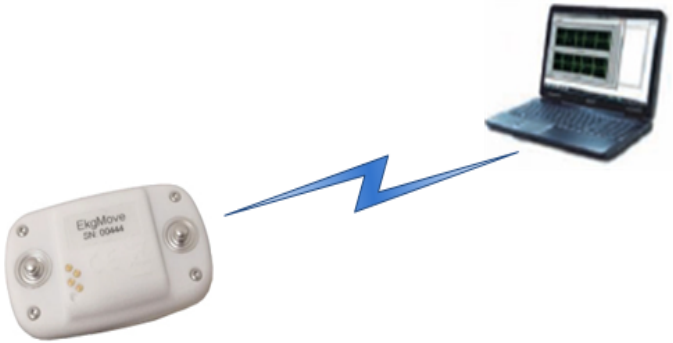
Major outcome

1. INCREASE OUR UNDERSTANDING
2. ADVANCE NOVEL HOLISTIC MONITORING AND ANALYSIS APPROACH
3. GUIDANCE OF DIAGNOSTIC WORKOUT
4. DETECT LIFE THREATENING SEAZURES

ARMOR Demonstrators

Demonstrator 1 (Off the Shelf Platform)

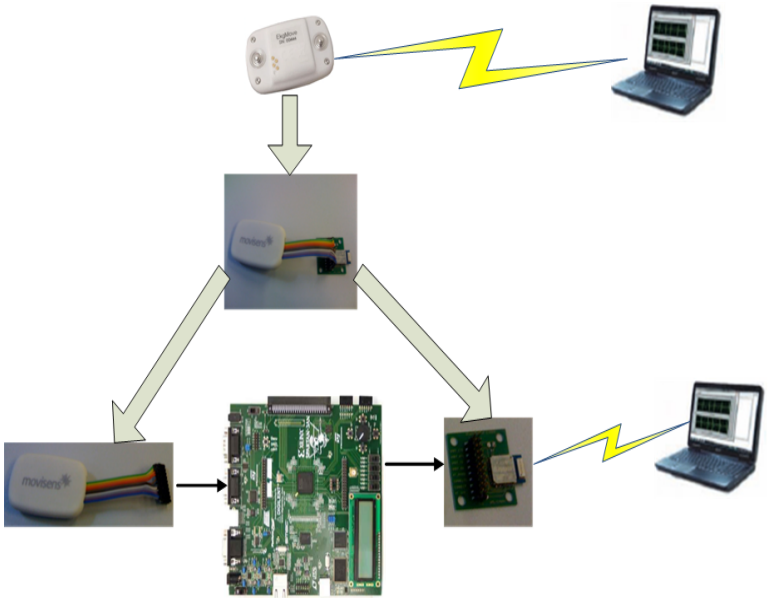
- Movisens Solution
  - ✓Closed-proprietary Solution
  - ✓Support for various sensors
  - ✓Robust casing
  - ✓Bluetooth Wireless communication Interface Support



ARMOR Demonstrators

Demonstrator 2 – ARMOR Experimental Setup

- Hardware Implementation of AES encryption algorithm
- Integration of the encryption module into the ARMOR CPS data flow



ARMOR Demonstrators

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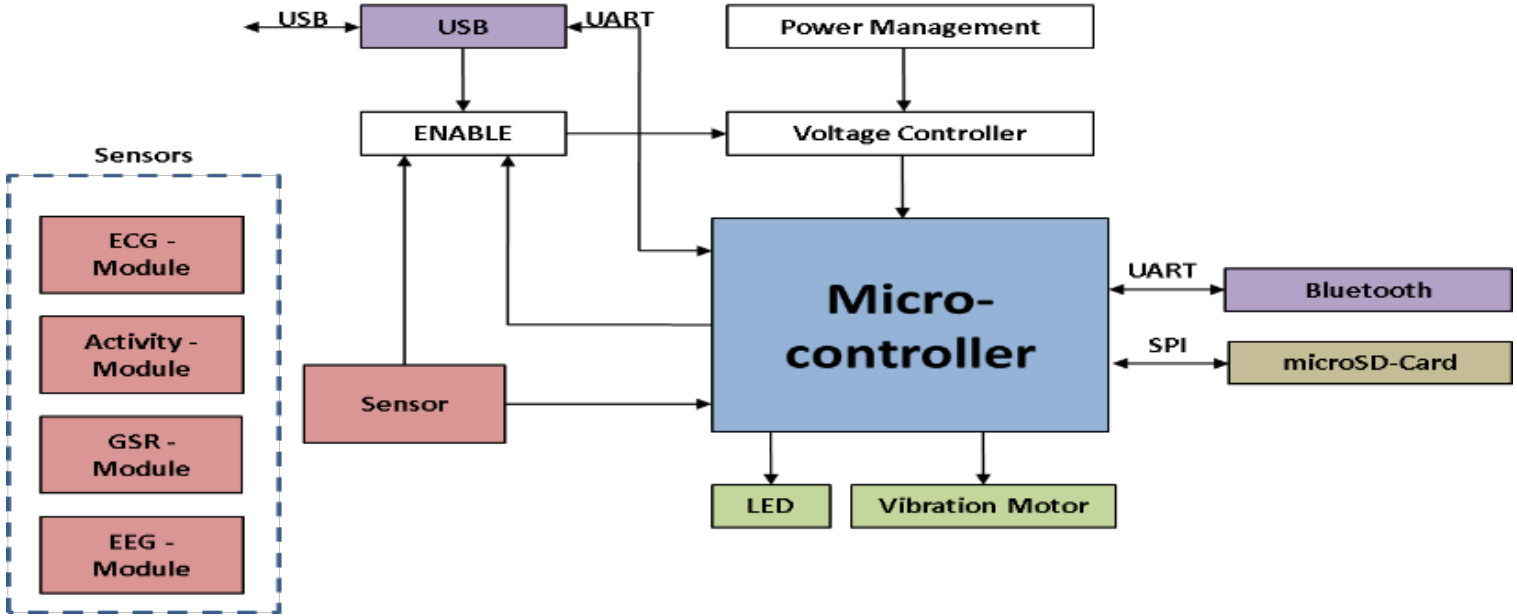
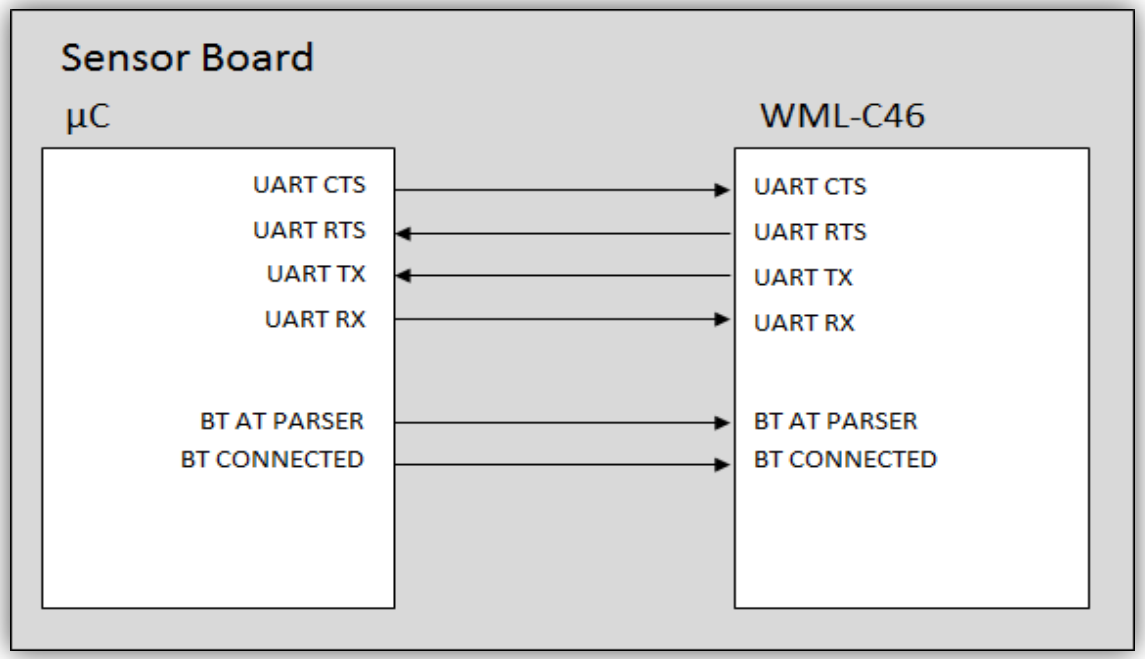


EkgMove Sensor Architecture

ARMOR Demonstrators

Demonstrator 2 – ARMOR Experimental Setup



ARMOR Demonstrators

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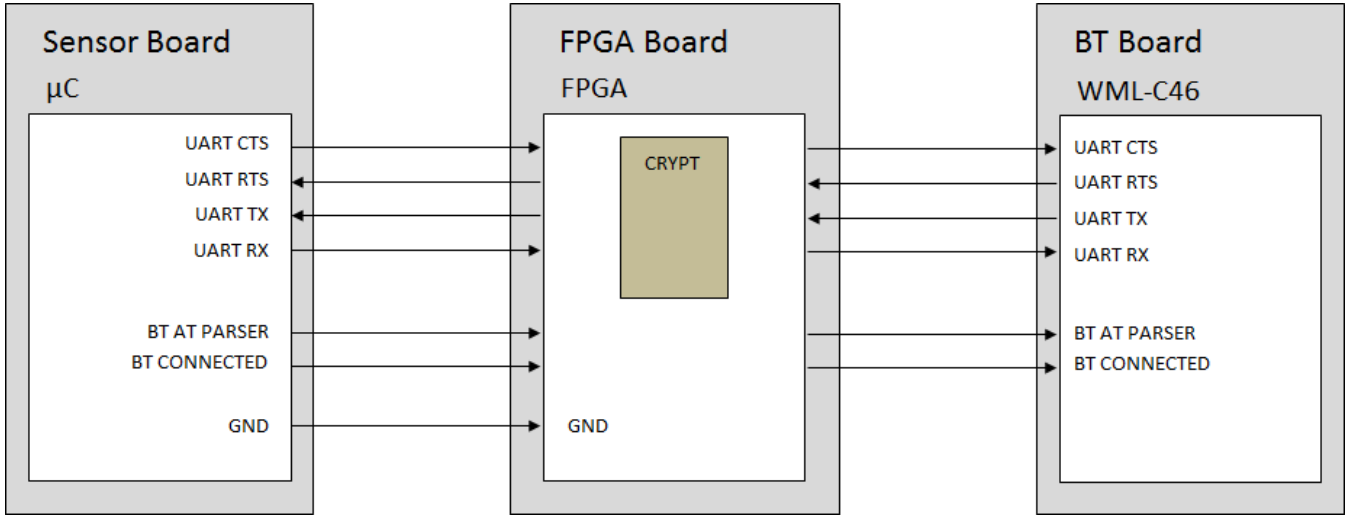
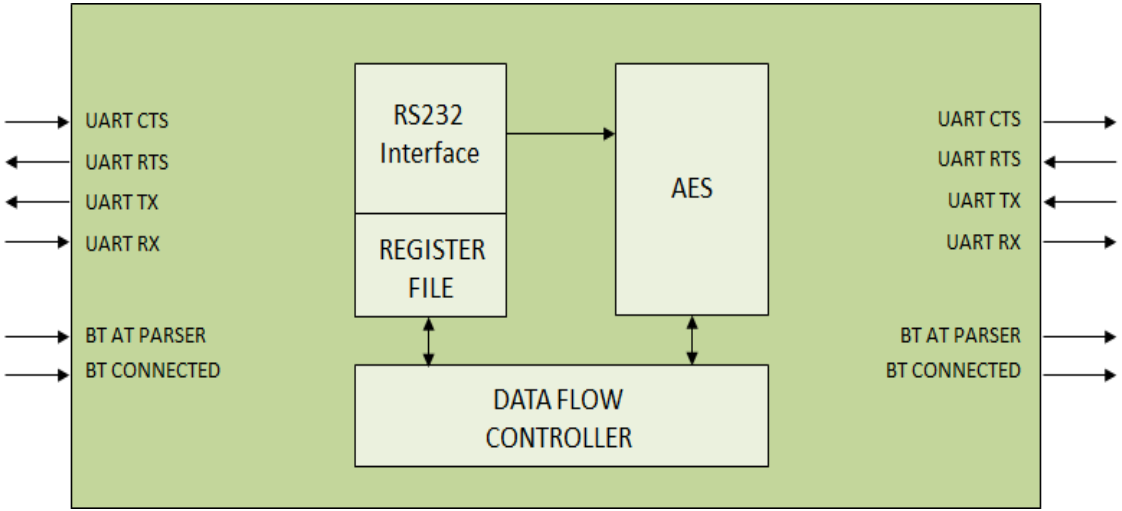


End-to-end integration to ARMOR CPS

ARMOR Demonstrators

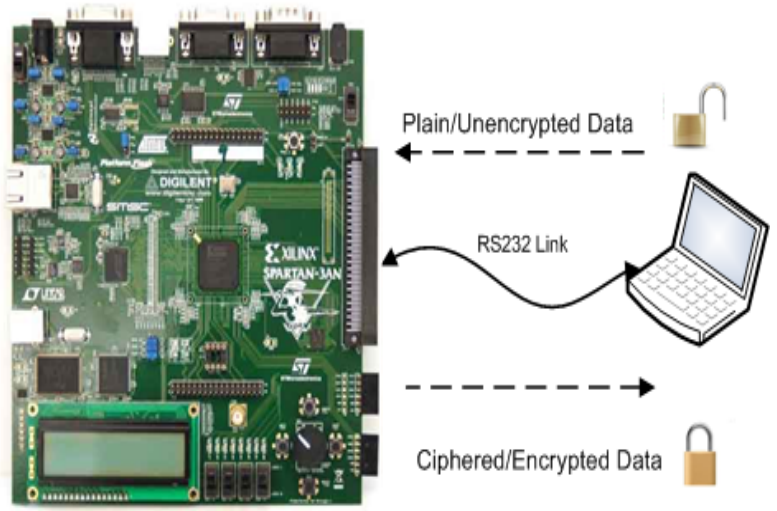
Demonstrator 2 – ARMOR Experimental Setup



Internal components of encryption module

Demonstrator 2 – ARMOR Experimental Setup

- Encryption module implementation details
  - ✓ Ultra low power
    - Power dissipation in the range of 6 to 11 mWatts
  - ✓ Adequate performance
    - >37Mbps for Xilinx Spartan-3 technology 200MHz
  - ✓ Compact Implementation
    - Highly competitive silicon area requirements



Demonstrator 3 (Off the Shelf Platform)

+ Shimmer Solution
  - ✓ Open Solution
  - ✓ Highly Configurable
  - ✓ Various sensors
  - ✓ All sensor come as daughter boards adding to the flexibility
  - ✓ Multiple wireless communication interfaces