Compiler Technologies: a Tool for Innovation

Workshop "Compiler Technologies: a Tool for Innovation"

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The CAPSARII Approach to Cyber-Secure Wearable, Ultra-Low-Power Networked Sensors for Soldier Health Monitoring

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The aim of **CAPSARII** is to design a *smart textile/wearable platform* along with an ICT framework intended to present **health data** and **insights tailored for military personnel.**

This initiative aligns with the *Internet of Battlefield Things* **(IoBT)** and utilizes **Artificial Intelligence and edge computing** to enhance the tracking of **soldiers**' psycho-physical conditions and **performance** by using a network of interconnected devices equipped with sensing abilities to improve **situational awareness** and **operational efficiency**.

- SEA SKY TECHNOLOGIES Srl **(Coordinator)** - *Italy*
- BORN GMBH KNITWEAR FOR FASHION & ENGINEERING - *Germany*
- IKERLAN S. COOP - *Spain*
- LWT3 Srl - *Italy*
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- POLITECNICO DI MILANO - *Italy*
- QUAESTA AI Srl - *Romania*

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CAPSARII Project Goals and Use Cases

Use Case 1: Warfighters in harsh environments

- Monitors health status of individual soldiers and teams
- Prevents stress and fatigue-related accidents

Use Case 2: Pilot fatigue monitoring

- Provides awareness of crew members' fatigue levels
- Suggests personalized countermeasures

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Strategic Objectives of CAPSARII

Monitoring Capabilities	Physiological parameters Movement parameters Environmental parameters
Tactical Decision Support	Support at the edge
Data Management	On-field and Batch Analysis Data ingestion and storage
Security and Confidentiality	Military grade communications
Usability of Wearable System	Harsh environments

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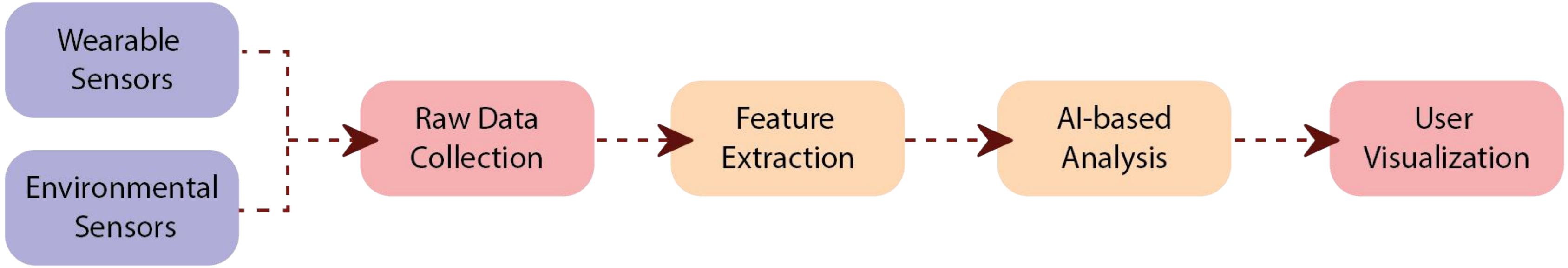
IoBT Concept and Architecture

- Concept of **Internet of Battlefield Things** (IoBT)
  - Interconnects **military-grade equipment**
  - **Protected IoT** computing architecture
- Continuous, interconnected process
  - Ensures **efficient data flow**
  - Analysis **to** and **from wearable** devices



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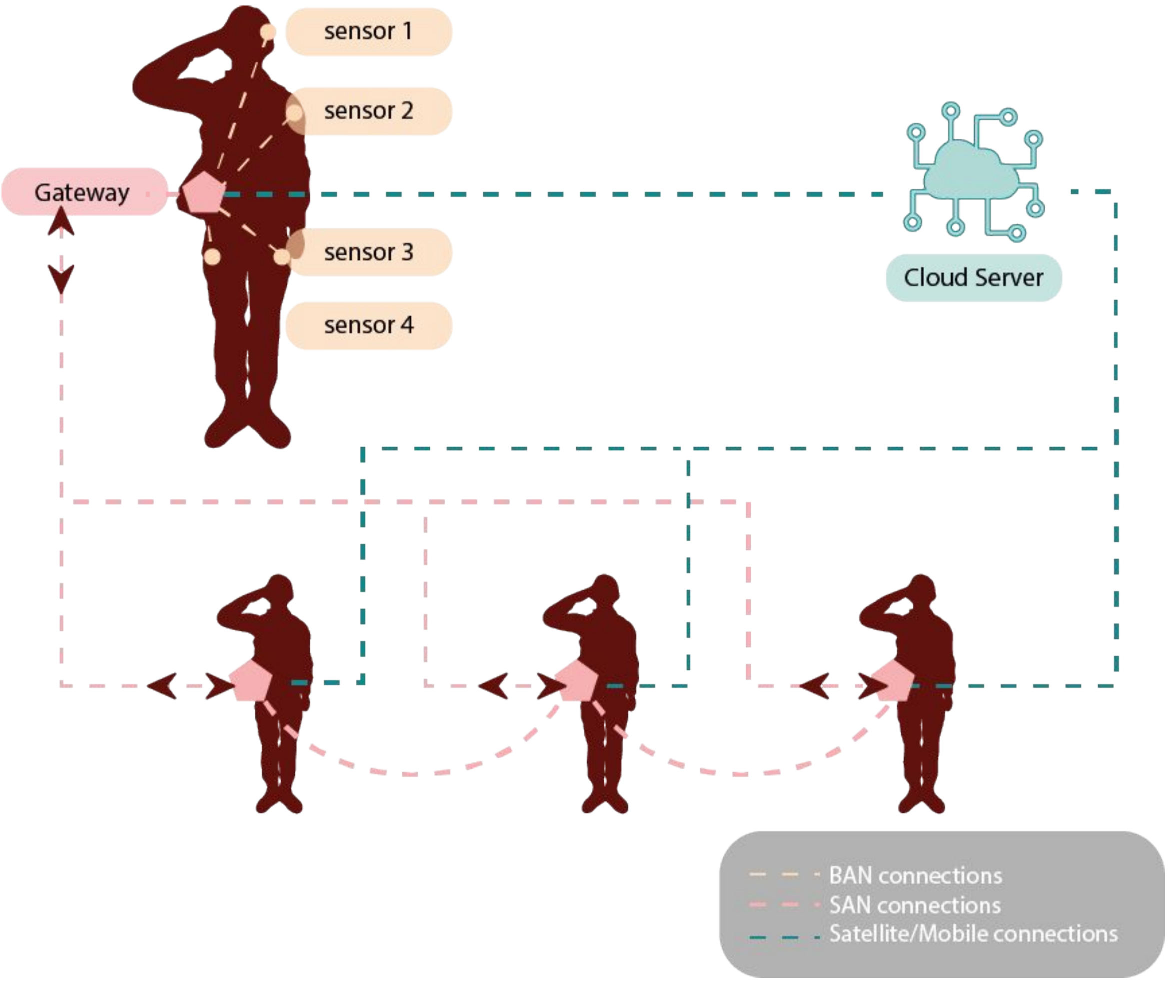
Warfighters in Harsh Environments

Real-Time Physiological Status Monitors (RT-PSM) provided by military wearable technology for actionable physiological status information, from:

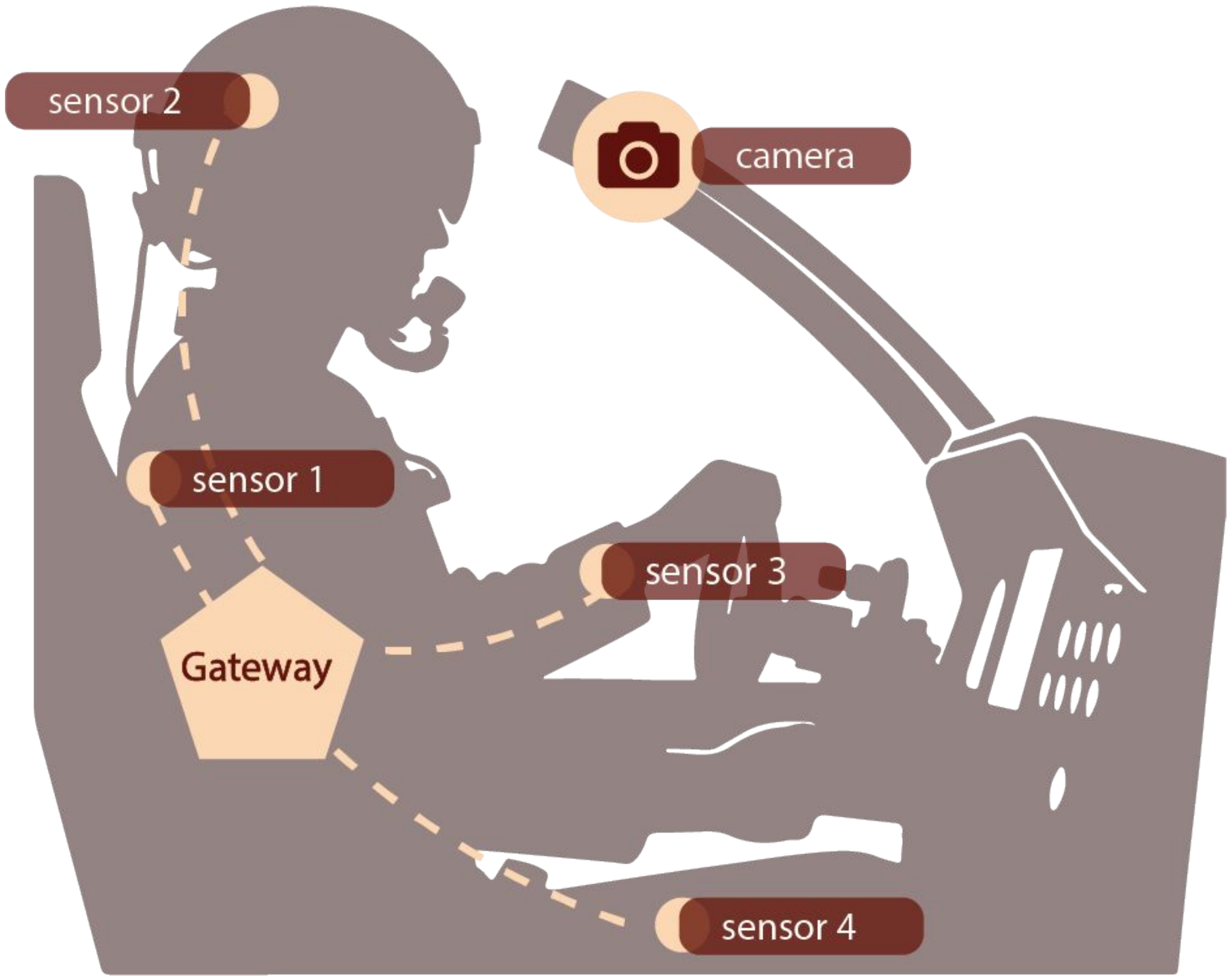
- Body Area Network (**BAN**)
    - Conveys physiological information
- Squad Area Network (**SAN**)
    - Enables intra-squad communications
    - Monitors and predicts physiological status and health conditions
    - Environmental conditions



Pilot Fatigue Monitoring

Pilot Fatigue Monitoring with sensors on BAN and Cockpit

- Increasing attention due to impacts on aviation safety and service member health
- Related to circadian pacemaker and need for sleep/rest
- **Personalized biomathematical models** can guide crew members on expected fatigue levels



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Challenges in Use Case Implementation

Low-Power Embedded device

- Real-time processing (Low-Power Embedded AI)
- Low energy dissipation
- Specific Machine learning techniques
- Communication reliability
- Performance and security

Data Management

- Monitoring stress and fatigue
- Tracking physiological factors
- Assessing physical health
- Evaluating environmental situations
- Decision-making process

Key Components of Technical Approach

Full Integration of Wearable Technologies	Fabric with electronic components Advanced functionality such as sensing, actuation, communication, and data processing
Advanced Data Analytics	Utilizes AI-model optimization
User-Centric Interfaces	Focuses on ease of use and accessibility
Collaborative Cloud-Based Strategies	Encourages collaboration among European Defence
IoT Architecture	Supports the co-design of hardware and software
Ultra-Low Power AI Processors	New generation of energy-efficient processors

Data Collection to the Edge

Real-time Data Collection

- Wearable devices collect physiological, movement, and environmental parameters
- Operational metrics can be gathered using a mesh network

Edge Computing Systems

- Data is processed on edge-computing systems
- Ensures rapid and localized analysis

Edge Analysis

- Initial processing and evaluation of data near the source
- Occurs on wearable devices or within the near network

Rapid Decision Making

- Localised analysis enables quick decisions
- Minimises latency in acquiring critical information

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From Edge to Server

Initial Analysis at the Edge

Data is first analyzed at the edge

Ensures quick initial insights

Transmission to Centralised Server

Relevant data is sent to a central server

Allows for further processing and storage

Generation of Complete Information

Ensures comprehensive data analysis

Wearable devices can download processed data

Optimisation of Wearable Devices

Processed data enhances device functionality

Learning and Transfer Learning

Transfer Learning

- Enables training a model on one task and repurposing it for a related task
- Saves computational time and resources
- Improves performance with limited data

Transfer Learning Approaches

- Fine-tuning: Adjusting the model with new task data
- Feature extraction: Using the backbone of the first model as a feature extractor

Meta Learning

- Enables models to adapt to new tasks without forgetting previous ones
- Addresses the issue of catastrophic forgetting

Federated Learning

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Optimisation for Efficiency

Challenges of AI Model Complexity

- Increasing complexity with different situations/environments/parameters
- Deployment issues on resource-constrained devices like smartphones and IoT sensors
- Limitations in memory, storage, and energy compared to data center servers

Cloud Computing Concerns

- Greater processing power, but…
- …Latency and security concerns due to physical distance and data transmission risks

Model Compression Techniques

HW/SW Co-Design Methodology

Importance of Tailoring Hardware and Software

Applications like Edge AI have strict constraints on energy, power, and size

Precise tailoring of hardware and software is necessary to meet application requirements

HW/SW Co-Design and Platform-Based Design

These methodologies allow exploration of various solutions

Configurable and reconfigurable hardware platforms are used

CAPSARII's HW/SW Co-Design Methodology

Centered around a secure RISC-V microcontroller

Supports execution of control code, communication, and duty cycling

Selection of Accelerators

Processing-in-Memory (PIM) and GPU-like accelerators

Allows obtaining the right configuration for each application

HW/SW Co-Design Methodology

...tailoring HW and SW manually is a complex task

- the compiler can ease this activity. For instance, the **TAFFO** compiler extension developed by **Politecnico di Milano** and **NTNU** can help the designer in tailoring the software to the underlying HW platform, keeping into account accuracy requirements but minimizing the energy spent in costly floating-point computations

- Compilers are also critical in efficiently deploying AI on embedded platforms, particularly those that leverage ultra-low-power accelerators

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THANK YOU

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