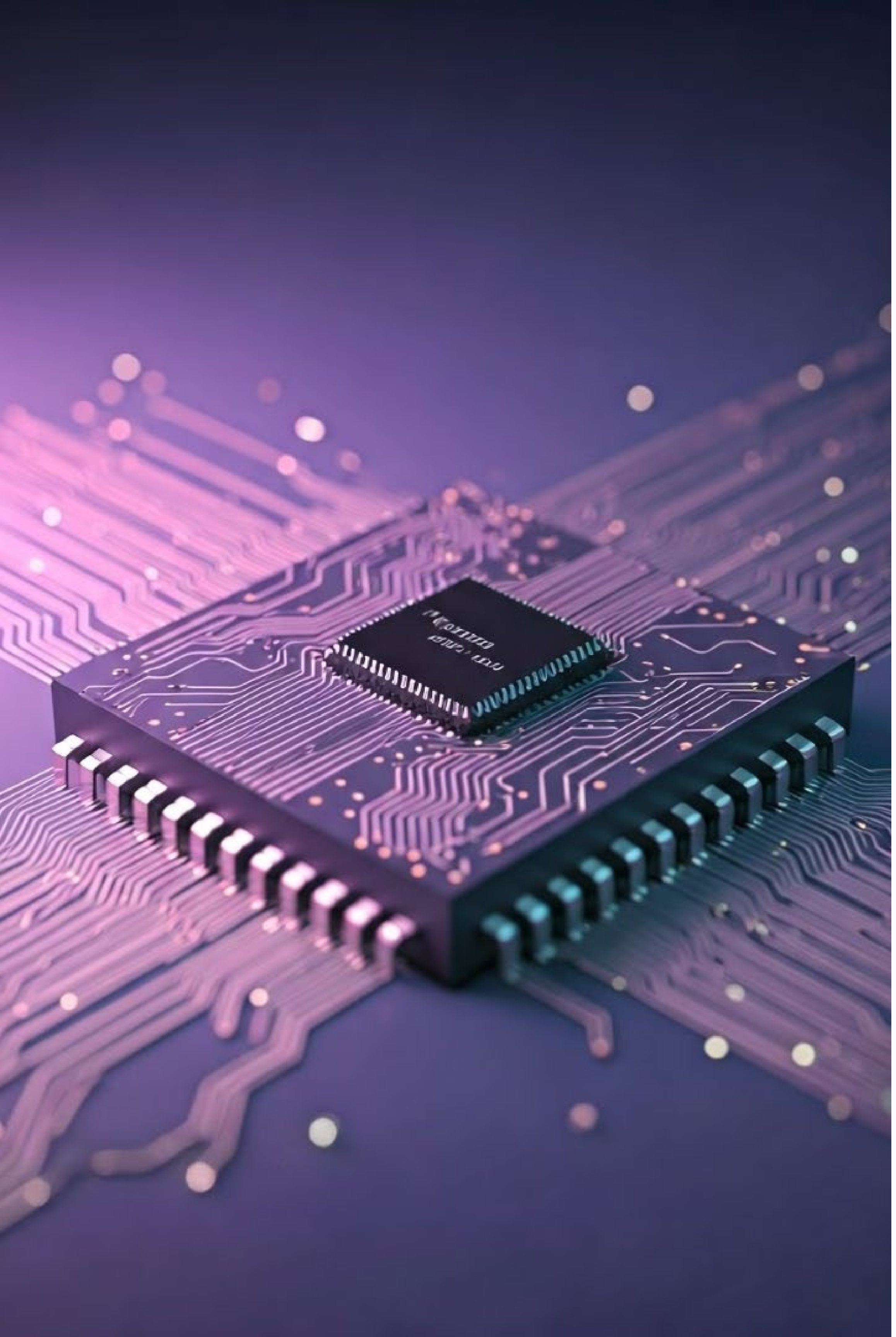

System on Chip (SoC): A Practical Implementation on Intelligent Neurosystems

Joint ICTP-IAEA School on Detector Signal Processing and Machine Learning for Scientific Instrumentation and Reconfigurable Computing, 2025

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What is a System on Chip (SoC)?

1 Integration

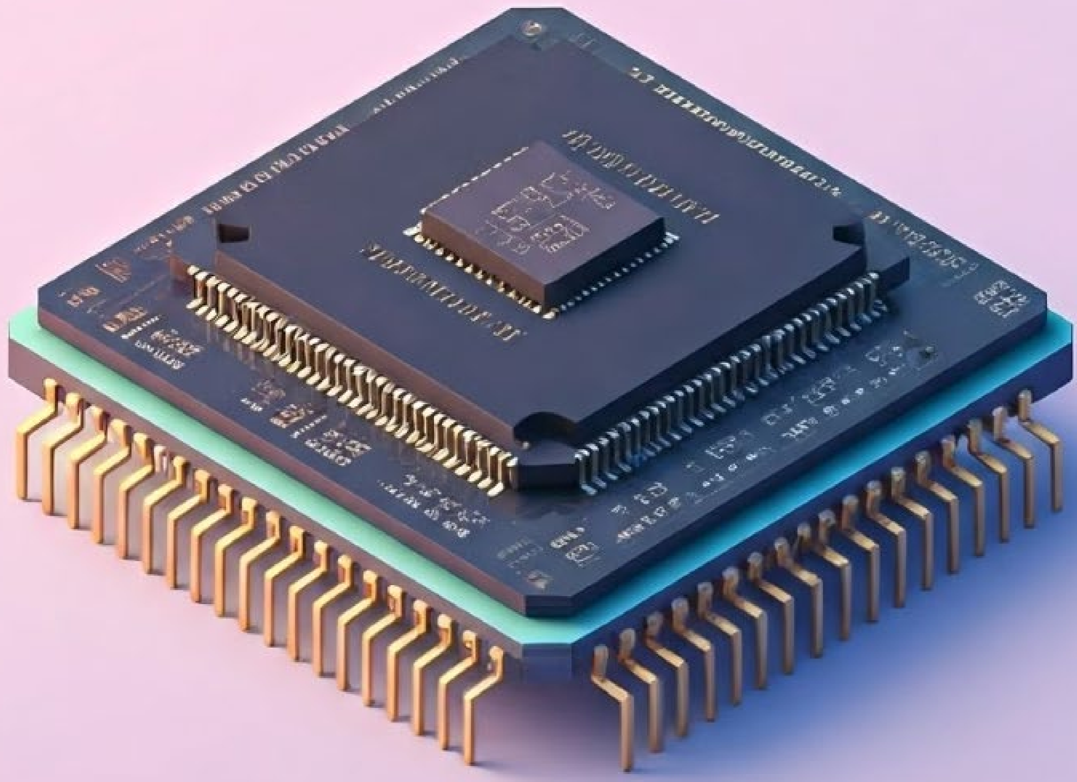
SoC combines multiple electronic components onto a single chip, reducing size and power consumption.

2 Functionality

It typically includes a processor, memory, and various interfaces for communication and data processing.

3 Efficiency

SoCs optimize performance by reducing signal travel time between components, enhancing overall system efficiency.



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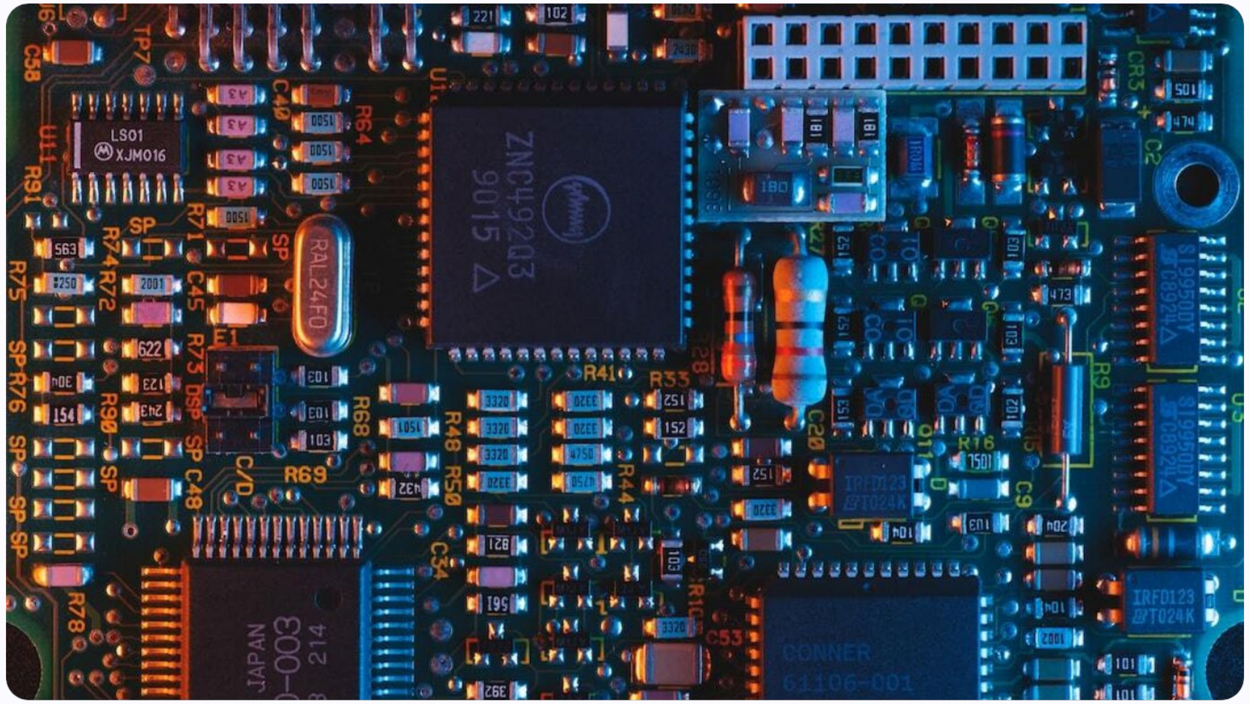
Types of SoCs

- **General-Purpose SoC:** Designed for broad applications such as smartphones and IoT, balancing performance and efficiency.
- **Application-Specific Integrated Circuit (ASIC):** Customized for specific tasks, often used in high-performance applications like video processing and crypto mining.
- **Programmable SoC (PSoC):** Includes FPGA for post-manufacture customization, offering flexibility in functionality for diverse applications.



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Why do you need FPGA? PSoC?

Programmable SoC (PSoC)

1 Evolution

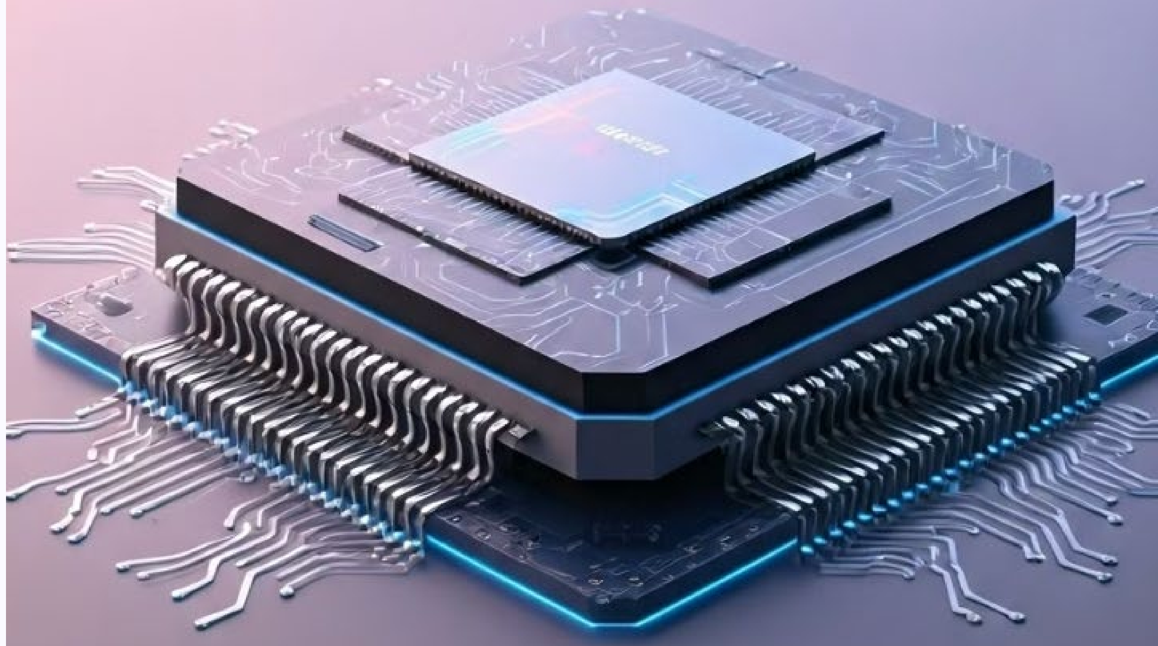
PSoCs emerged as a solution to combine the flexibility of FPGAs with SoC efficiency.

2 Integration

They integrate FPGA fabric with traditional SoC components, offering unprecedented customization possibilities.

3 Applications

PSoCs find use in diverse fields, from industrial automation to cutting -edge consumer electronics.



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Programmable SoC (PSoC)

FPGA

PSoC includes a reconfigurable FPGA fabric that enables customized hardware designs for specific applications.

Microcontroller/Microprocessor

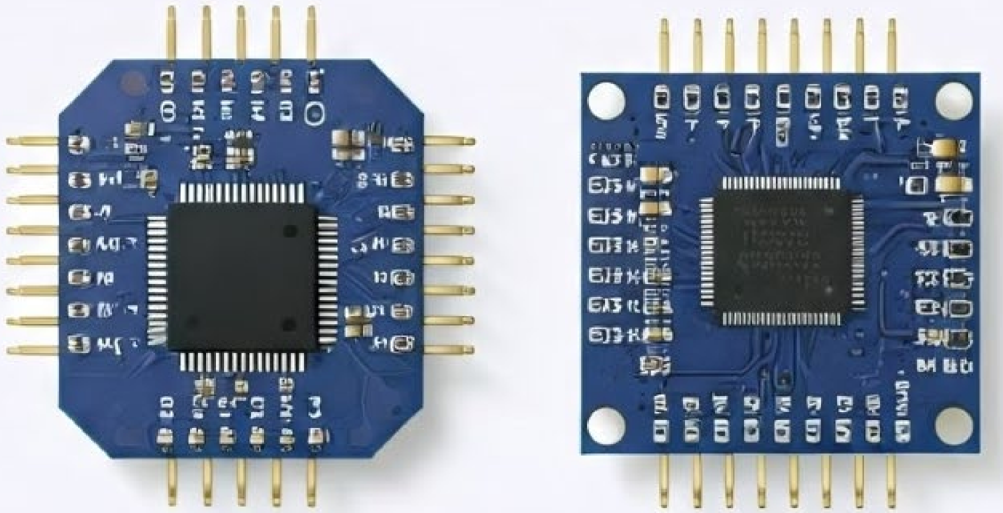
PSoC also incorporates a powerful microcontroller for managing and controlling the system's overall functionality.

Peripherals

PSoC features a wide range of integrated peripherals, such as analog-to-digital converters, timers, and communication interfaces.

Comparison of PSoC, Microprocessors, and Microcontrollers

Feature	PSoC	Microprocessor	Microcontroller
Cost	Lower cost	Higher cost	Lower cost
Power Consumption	Lower power consumption	Higher power consumption	Lower power consumption
Flexibility	Highly flexible due to FPGA	Less flexible, fixed architecture	Moderate flexibility
Processing Capabilities	High processing capabilities due to FPGA	High processing capabilities	Moderate processing capabilities



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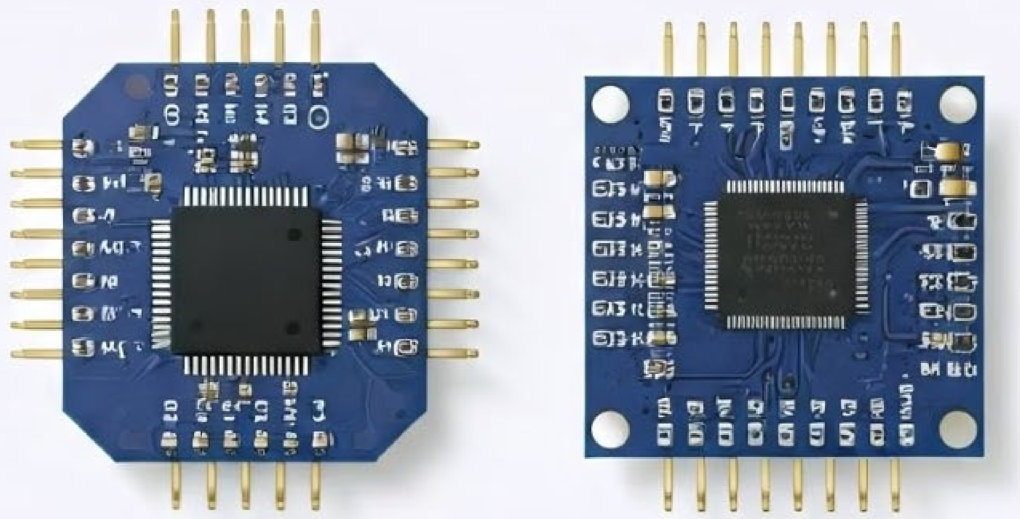

Advantages of PSoC over Microprocessors/Microcontrollers

1

Integration

PSoCs combine multiple functions, reducing overall system complexity and component count.

2

Customization

They offer unparalleled flexibility, allowing for tailored hardware solutions to specific problems.

3

Performance

Hardware acceleration capabilities enable PSoCs to outperform traditional microcontrollers in specific tasks.

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Case Study 1 : Human Emotion Detection

- In-Lab experiment (Audio Visual stimuli)
- Simulator based experiment (Driving game)

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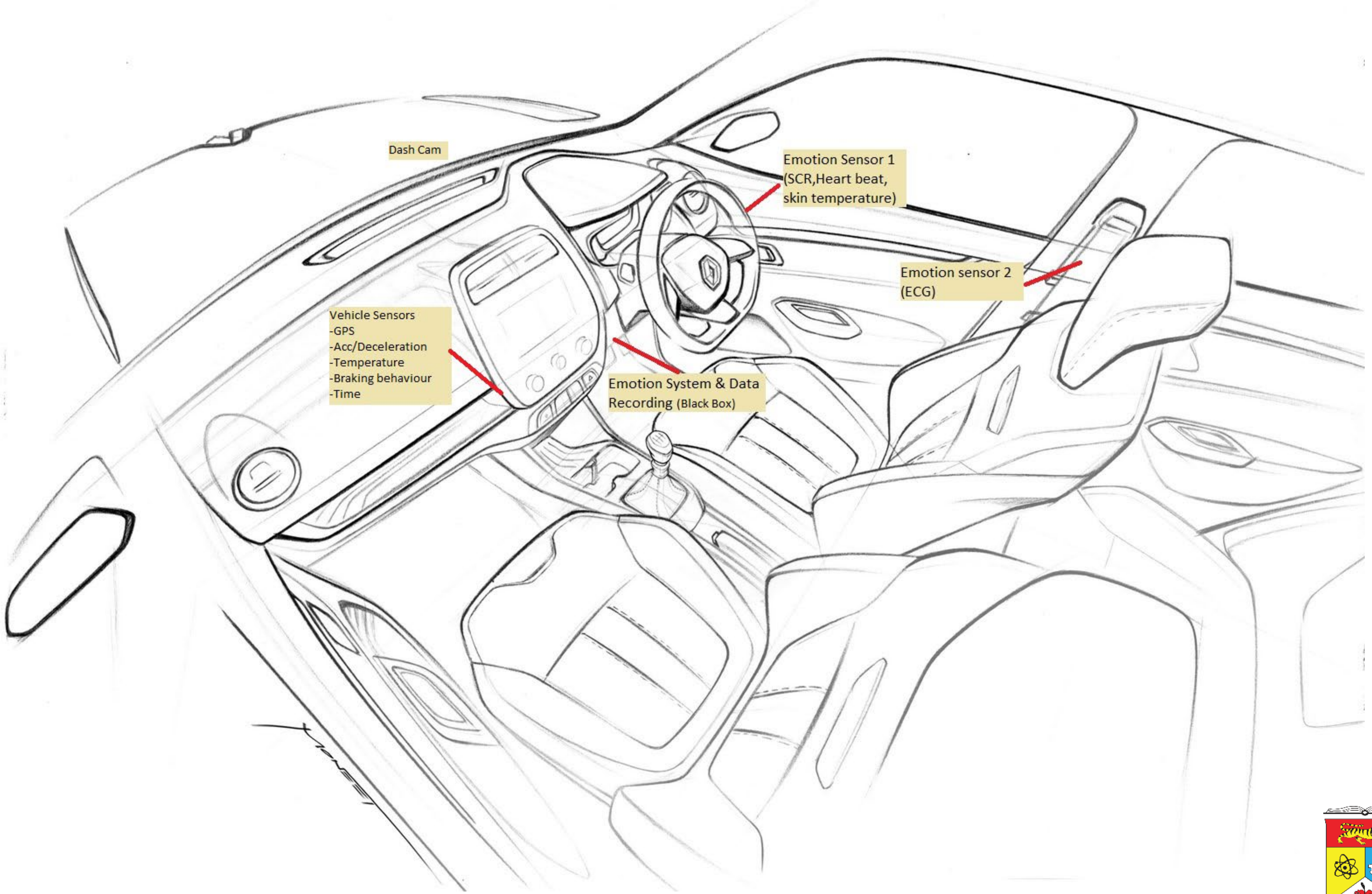
Proposed Prototype (patented)



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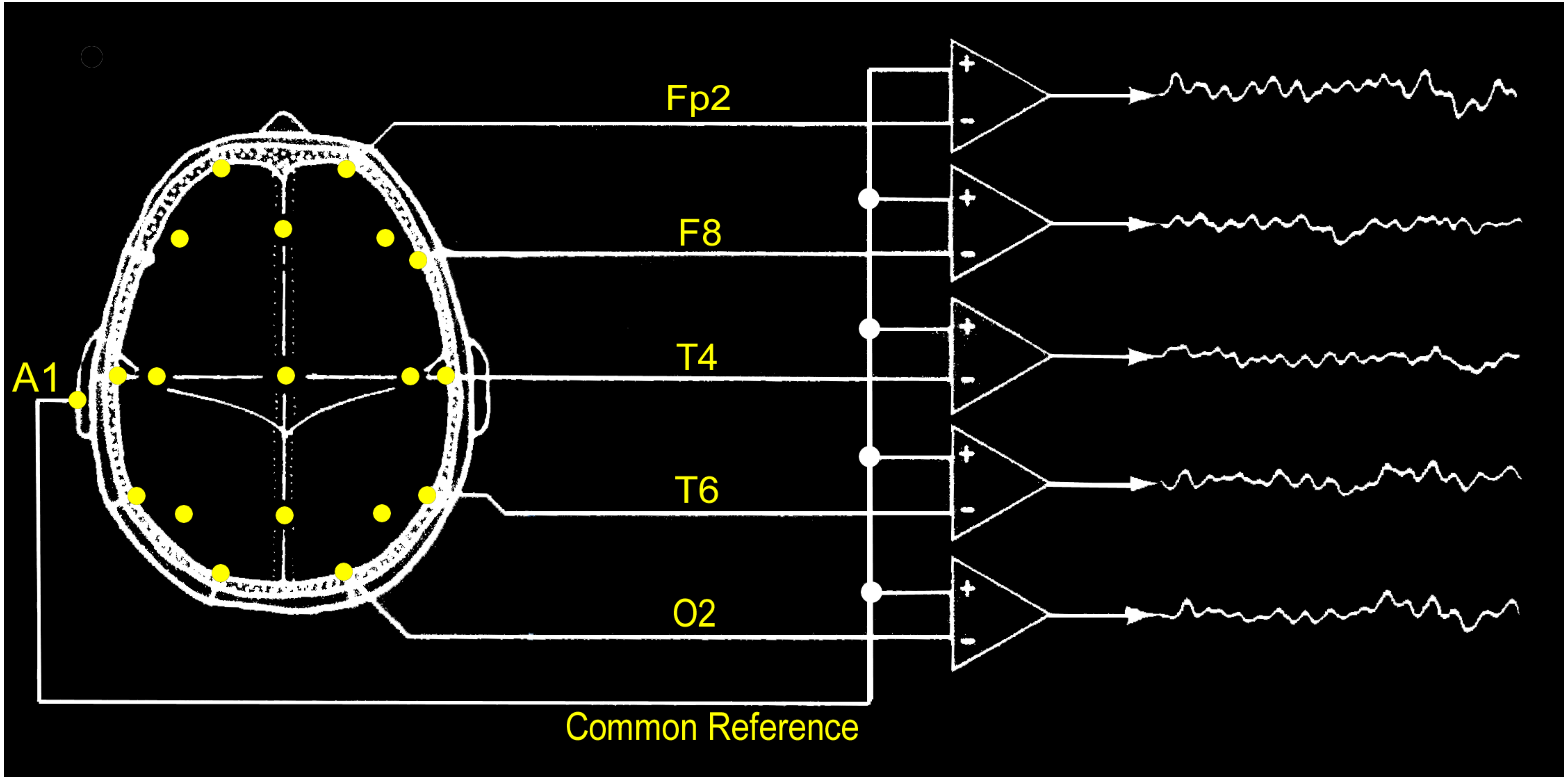
EEG electrode's location (10-20 system)



Human Emotion Recognition Experiment

Number of subjects

10 subjects (male and female)

Stimuli

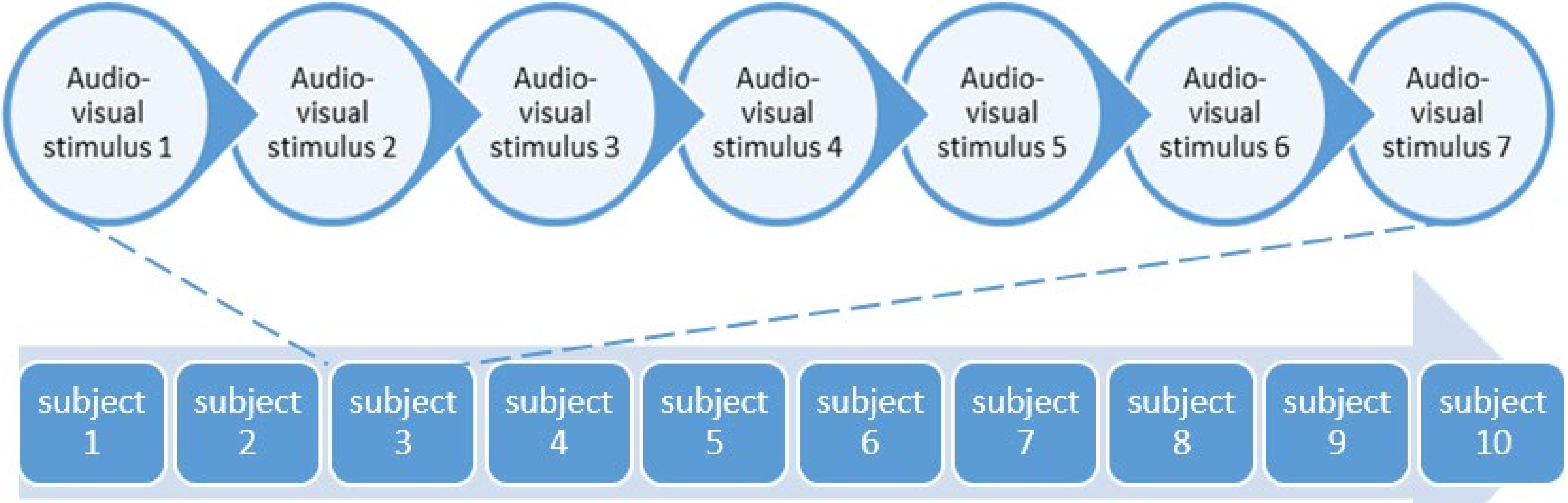
7 shorts video clips (without audio) corresponding to 7 emotions.

Number of emotions

7 emotions : Sad, Anger, Happy, Disgust, Fear, Surprise and Neutral

EEG channels

14 EEG channels using Emotive headset covering frontal, temporal, parietal and occipital regions



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Case Study 2: Using PSoC for Neuroprosthetic Applications

Overview of Neuroprosthetics and its Importance

1 Restoring Function

Neuroprosthetics aim to restore lost functions for individuals with disabilities due to neurological conditions.

2 Improved Quality of Life

These devices can enhance mobility, communication, and sensory perception, significantly improving quality of life.

3 Advancements in Neuroscience

Neuroprosthetic research contributes to a deeper understanding of the brain and nervous system.

Challenges in Neuroprosthetic Design and Implementation

Signal Processing

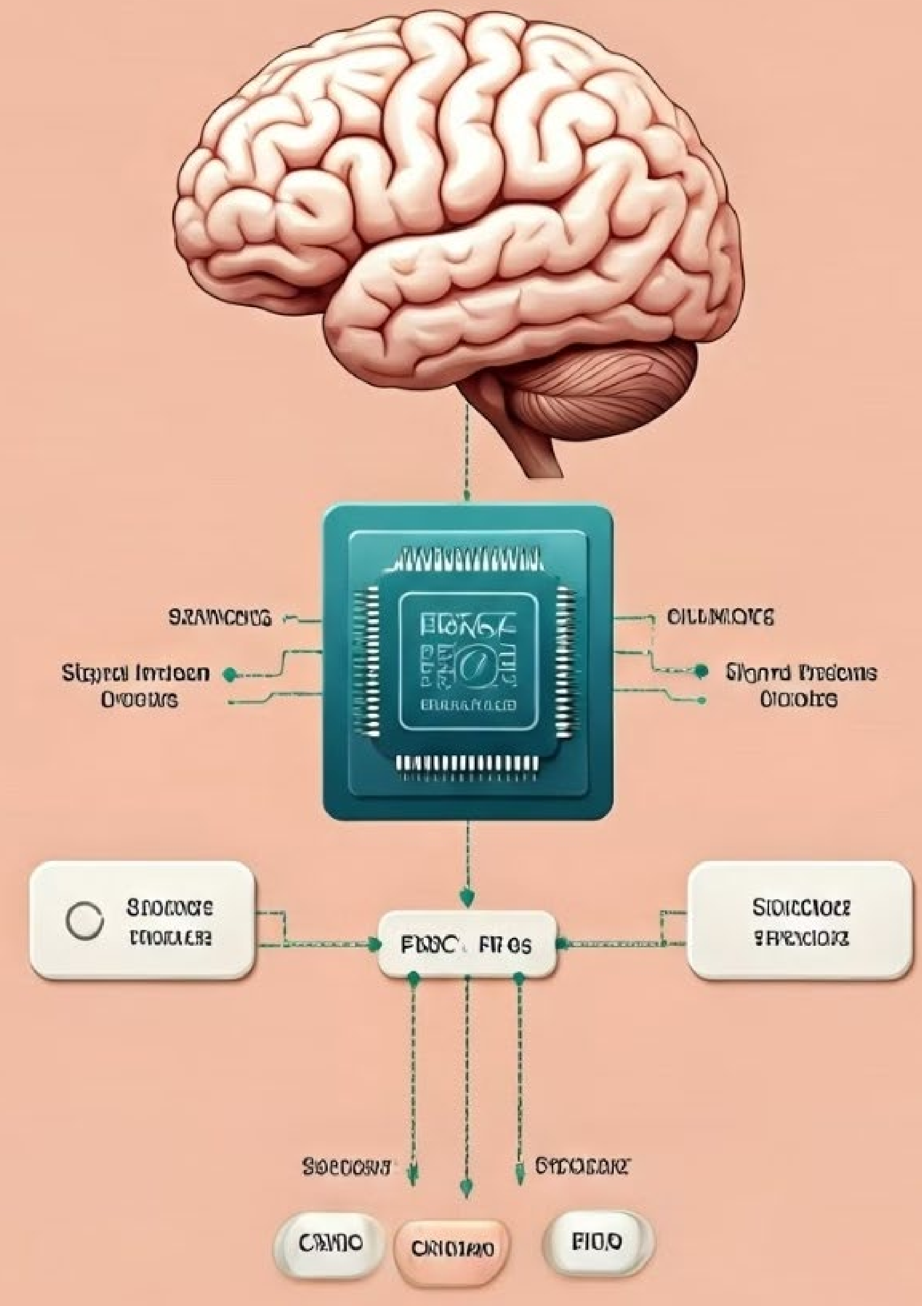
Accurate and reliable signal processing is critical for interpreting brain signals and controlling prosthetic devices.

Power Consumption

Prosthetics require efficient power management due to their continuous operation and the need for portability.

Biocompatibility

Ensuring that devices are safe and compatible with the body's biological environment is crucial for long-term use.



Integrating FPGA Capabilities in PSoC for Neuroprosthetics

1
Signal Acquisition

FPGA can acquire neural signals from electrodes attached to the head.

2
Signal Processing

FPGA allows for real-time signal processing, including filtering, noise reduction, and feature extraction.

3
Control and Communication

FPGA interfaces with the microcontroller and external devices to control prosthetic movements and transmit data.

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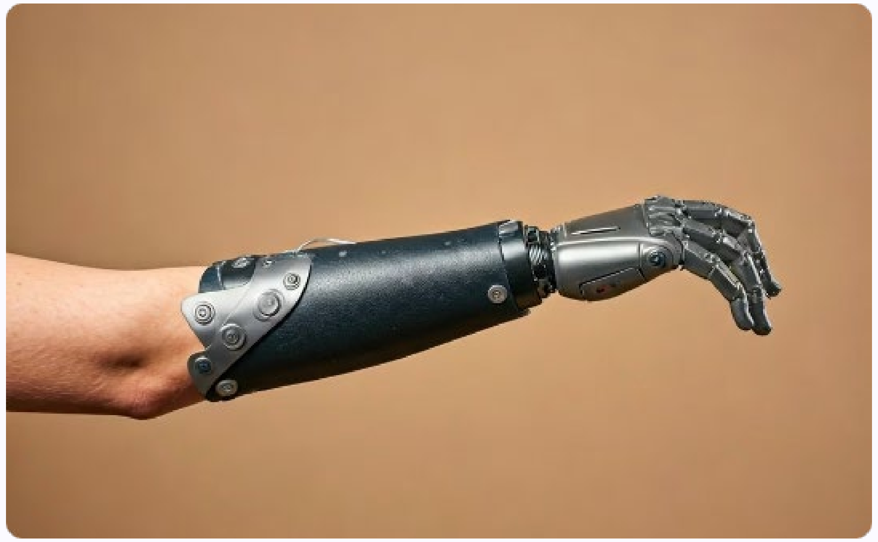
Real-World Examples of PSoC-based Neuroprosthetic Devices

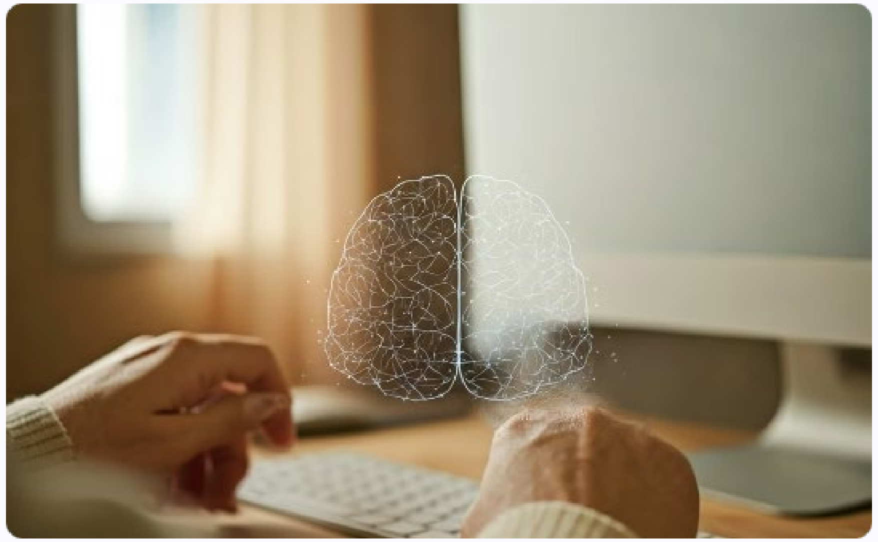


Prosthetic Arms

PSoC-based devices enable intuitive control of prosthetic arms, allowing users to grasp, manipulate, and perform complex movements.

Prosthetic Legs

PSoC facilitates precise control of prosthetic legs, providing a smooth and responsive walking experience.



Brain-Computer Interfaces

PSoC supports communication between the brain and external devices, enabling individuals to control computers or other devices using thought.

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Prosthetic Legs: Predicting upcoming movements

EXISTING BCI SYSTEM IS USING STATIONARY PC FOR PROCESSING.

COMBINE EEG AND EMG SIGNAL PROCESSING

REAL-TIME MOVEMENT PREDICTION (PARALLEL PROCESSING)

Requirements

- Should be as small as possible
- Ability to communicate with other systems (e.g. actuator)
- Integration of signal processing and machine learning
- Combination of multiple physiological data in parallel

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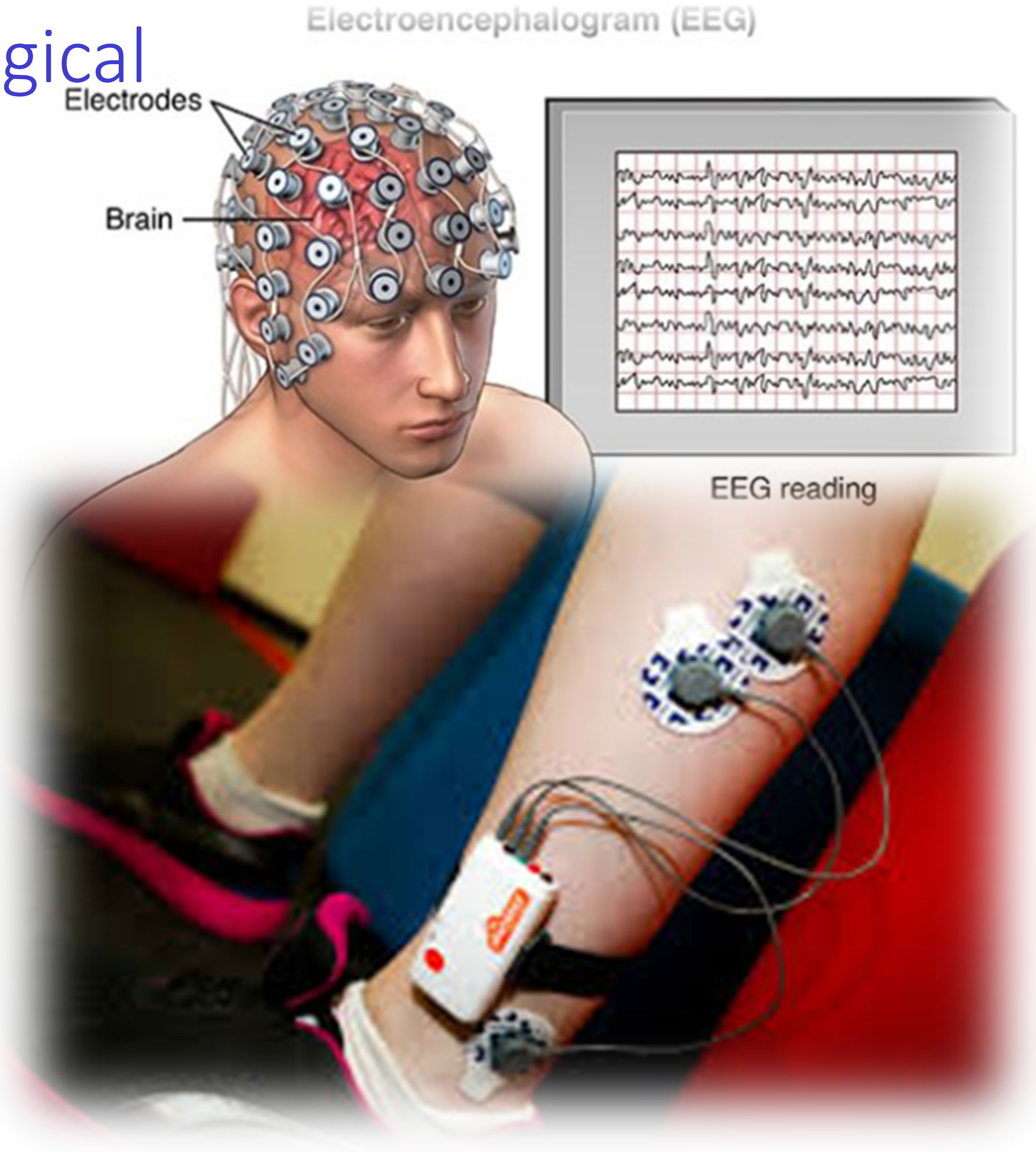
Importance of multiple physiological signals



- Different physiological signals, different properties and contain different information
  - Multi modalities has advantage over single modality
  - Combination of EEG, ECG, SCR and EMG improve the reliability of the prediction.

EEG and EMG for moving prediction

Detect movement intentions early using EEG

changes in the EMG can only be observed close to the actual movement onset.

Using EMG alone is not applicable to paralyzed patient and difficult for patients with tremor or spasms (depends on severity of paresis)

Combination can help to enhance the reliability of control commands of the device.

Upcoming movement prediction

EEG data can be used to detect/predict movements

- Event-related synchronization (ERD/ERS) and Motion-Related Cortical Potentials (MRCP)

SNR of raw EEG data is low hence computationally expensive algorithms needed to extract useful information.

- The computing hardware must guarantee high performance and low latency to maintain the earliness of predictions.

EMG measures electric potentials generated by active muscles

- EMG-based prediction is not suitable for paralyzed patients caused by spinal cord injuries.

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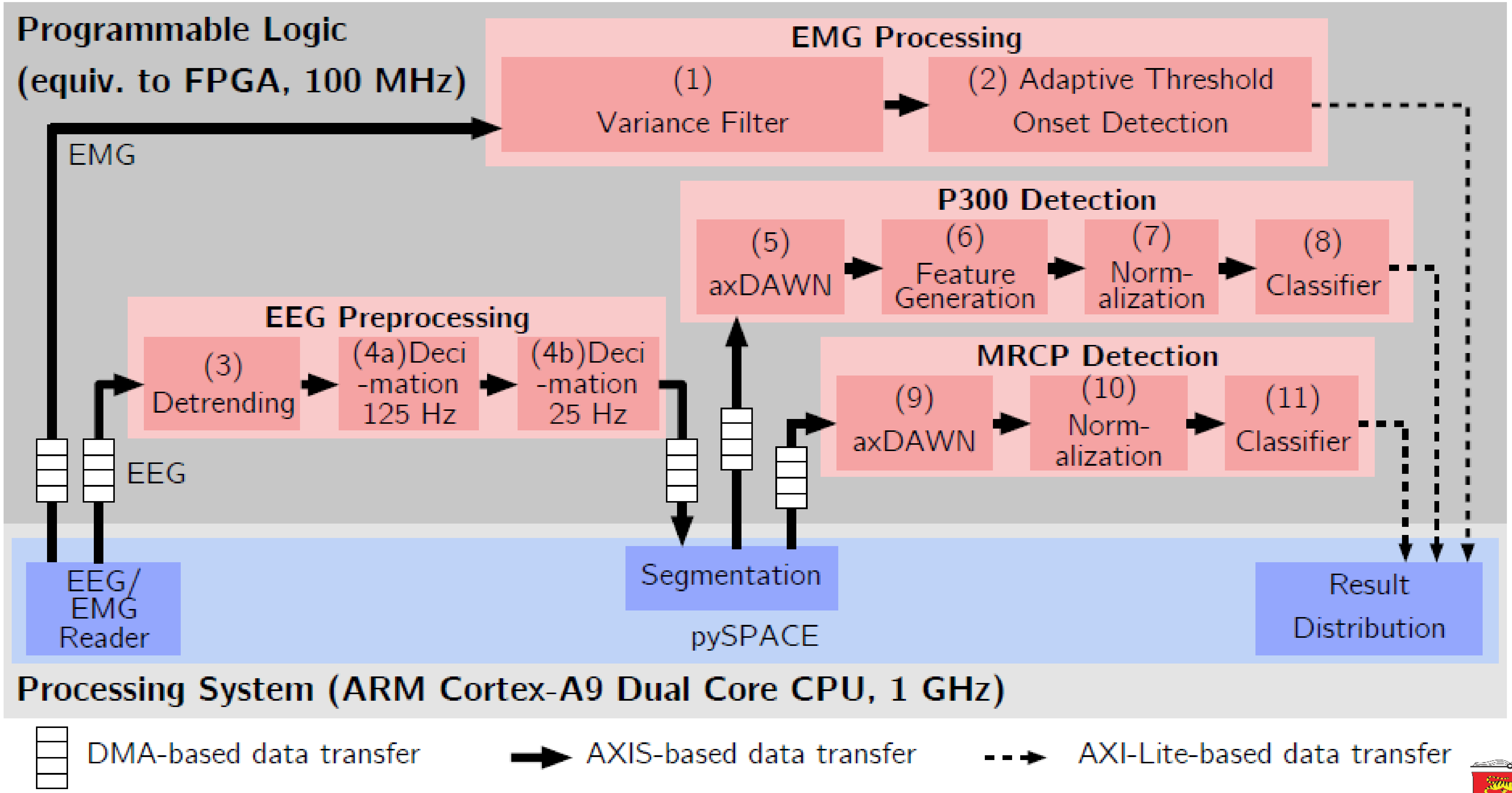
High-performance embedded computing systems are required that can employ a range of **different signal processing** and **ML techniques** to process the physiological data in **real-time** and have a **low power consumption**

PSoC system for upcoming moving prediction



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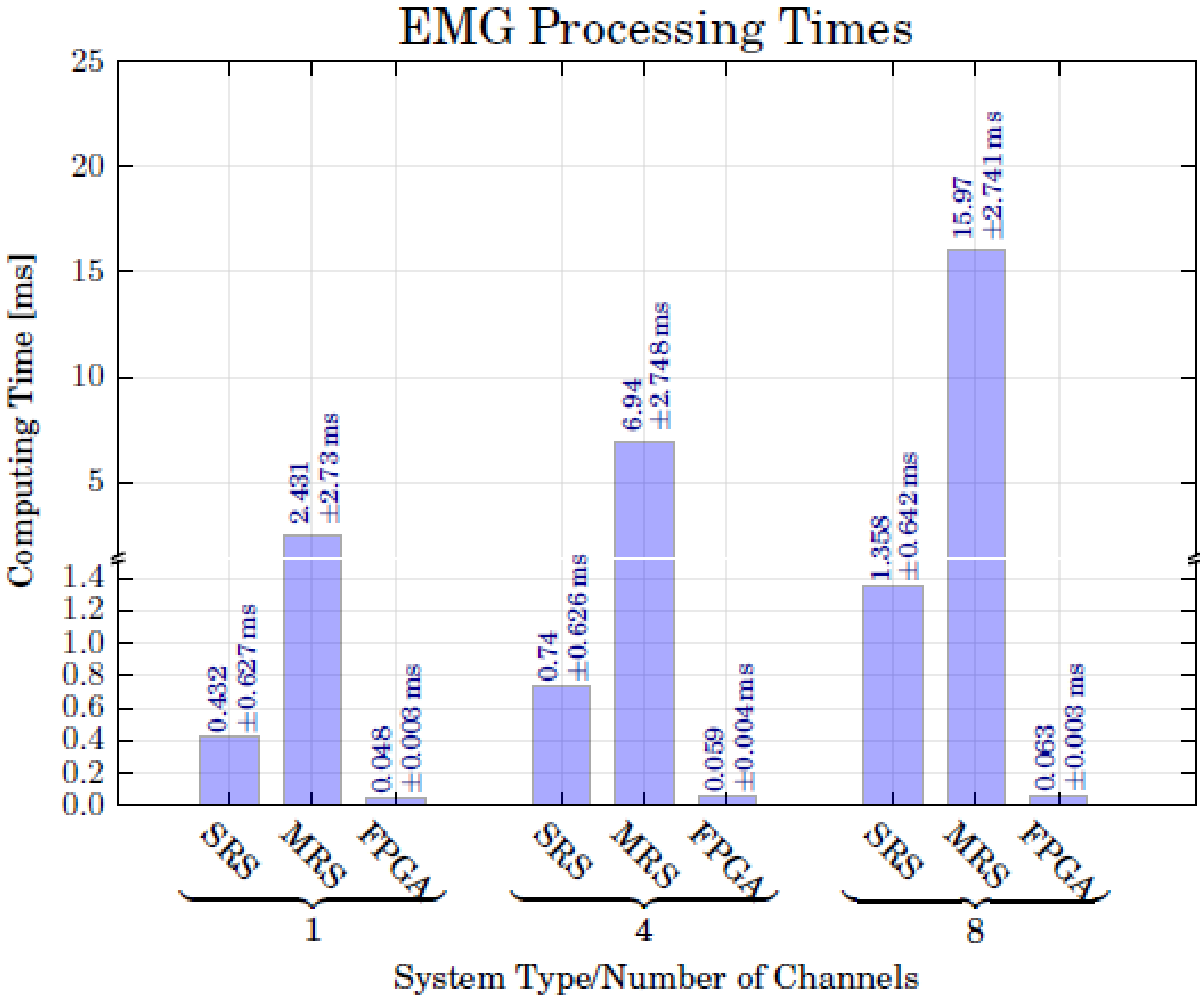
Processing time comparison (CPU vs FPGA) - EMG



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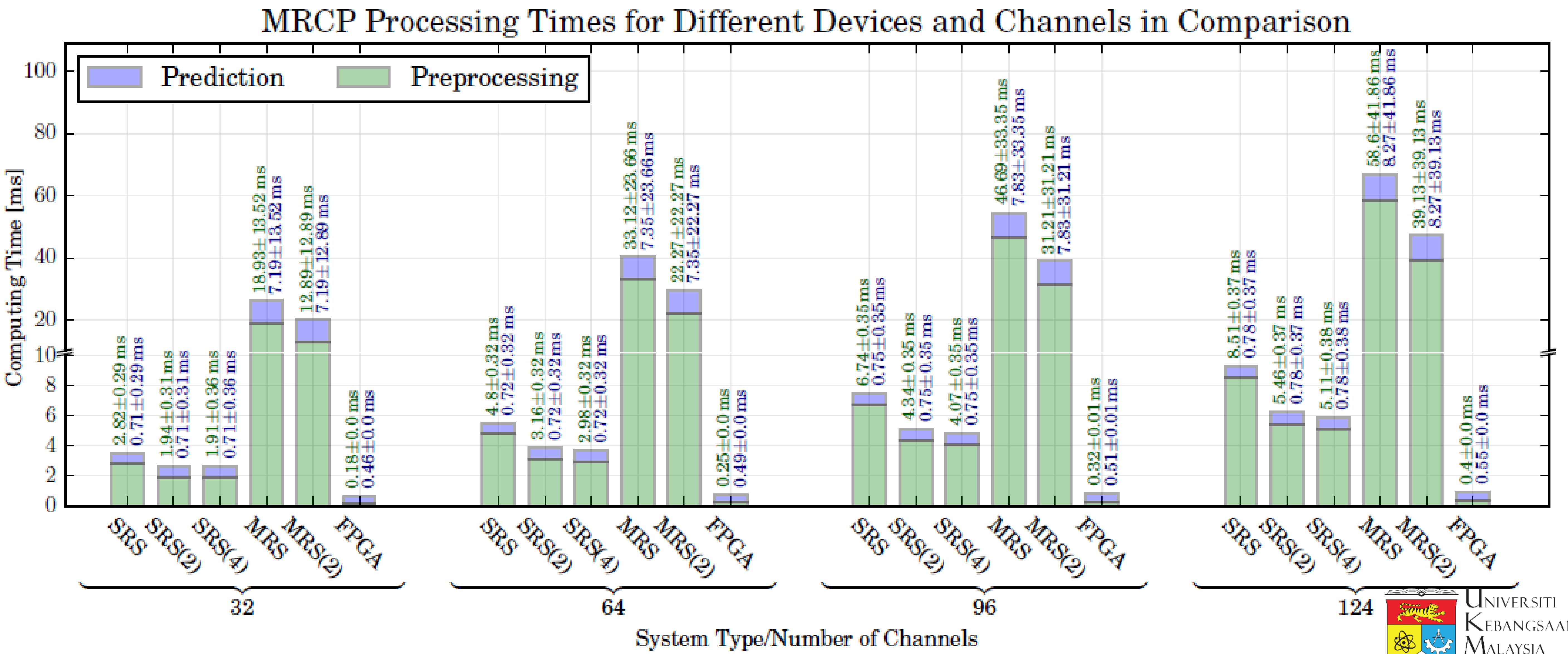
Processing time comparison (CPU vs FPGA) - EEG



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Power consumption comparison (CPU vs FPGA)

SRS	Idle	1 Core	2 Cores	4 Cores
EMG	119.8 W	130.2 W	130.2 W	130.2 W
MRCP	119.8 W	126.0 W	126.4 W	127.6 W
MaE, MoE	119.8 W	133.0 W	133.3 W	135.2 W
PaM	119.8 W	129.6 W	130.2 W	132.1 W
PaE	119.8 W	132.6 W	132.6 W	132.6 W
PaMaE, PaMoE	119.8 W	136.8 W	138.1 W	138.3 W
MRS	**Idle**	**1 Core**	**2 Cores**	
EMG	2.98 W	3.28 W	3.23 W	
MRCP	2.98 W	3.23 W	3.23 W	
MaE, MoE	2.98 W	3.30 W	3.61 W	
PaM	2.98 W	3.29 W	3.60 W	
PaE	2.98 W	3.31 W	3.64 W	
PaMaE, PaMoE	2.98 W	3.32 W	3.66 W	
FPGA	**Idle**	**Computing**		
EMG	3.45 W	4.12 W		
MRCP	3.45 W	4.12 W		
MaE, MoE	3.49 W	4.41 W		
PPaM	3.58 W	4.48 W		
PaE	3.53 W	4.49 W		
PaMaE, PaMoE	3.59 W	4.51 W		

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Cited from [1]

Conclusion and Future Trends in PSoC for Healthcare

PSoC technology holds immense potential for advancing healthcare systems and devices, offering **flexibility, customization, and efficiency** . Future trends include integration with artificial intelligence, device miniaturization, and developing more sophisticated neural or other physiological interfaces.

Thank You

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