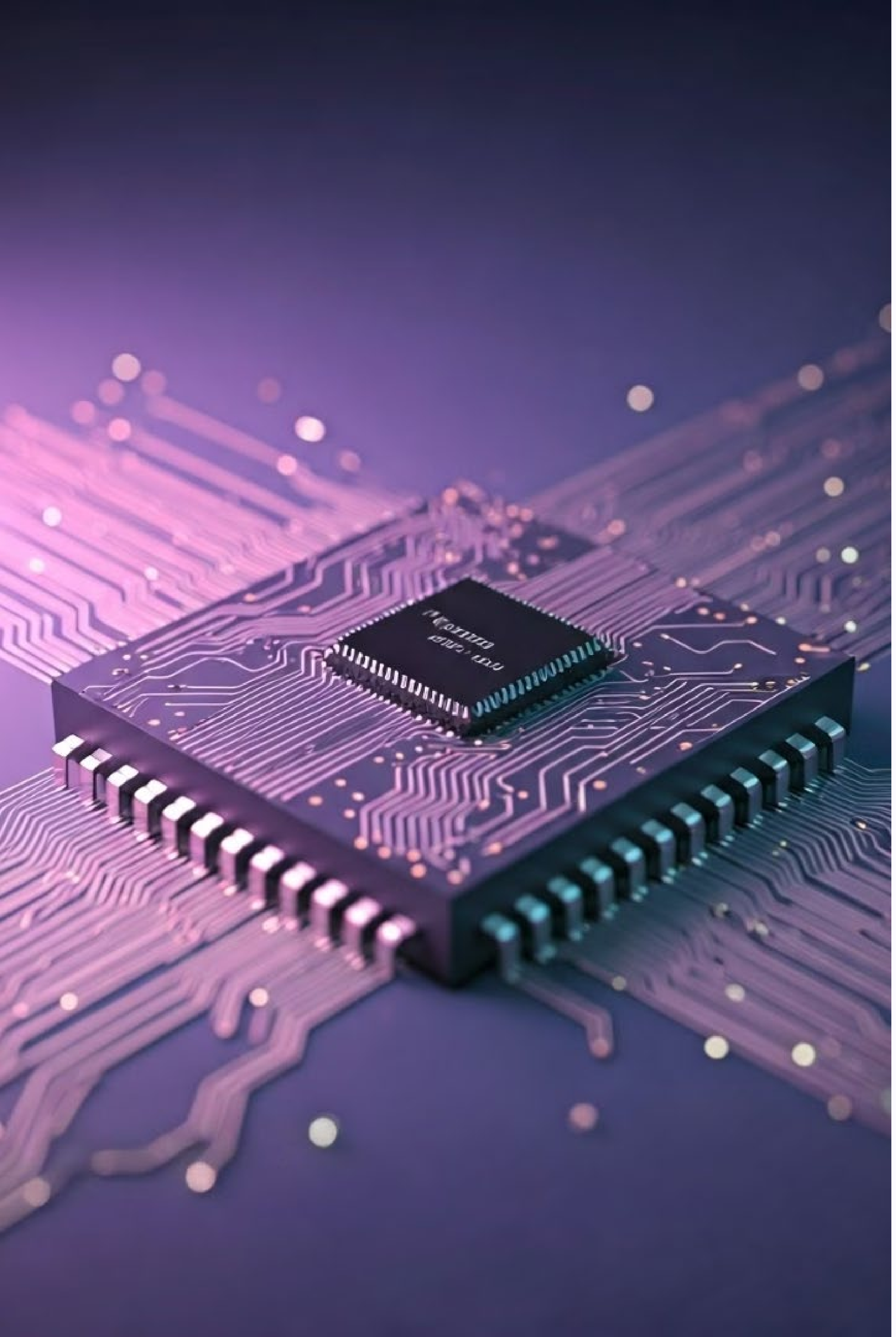


System on Chip (SoC): A Practical Implementation

Workshop on Fully Programmable Systems-on-Chip for Scientific Applications

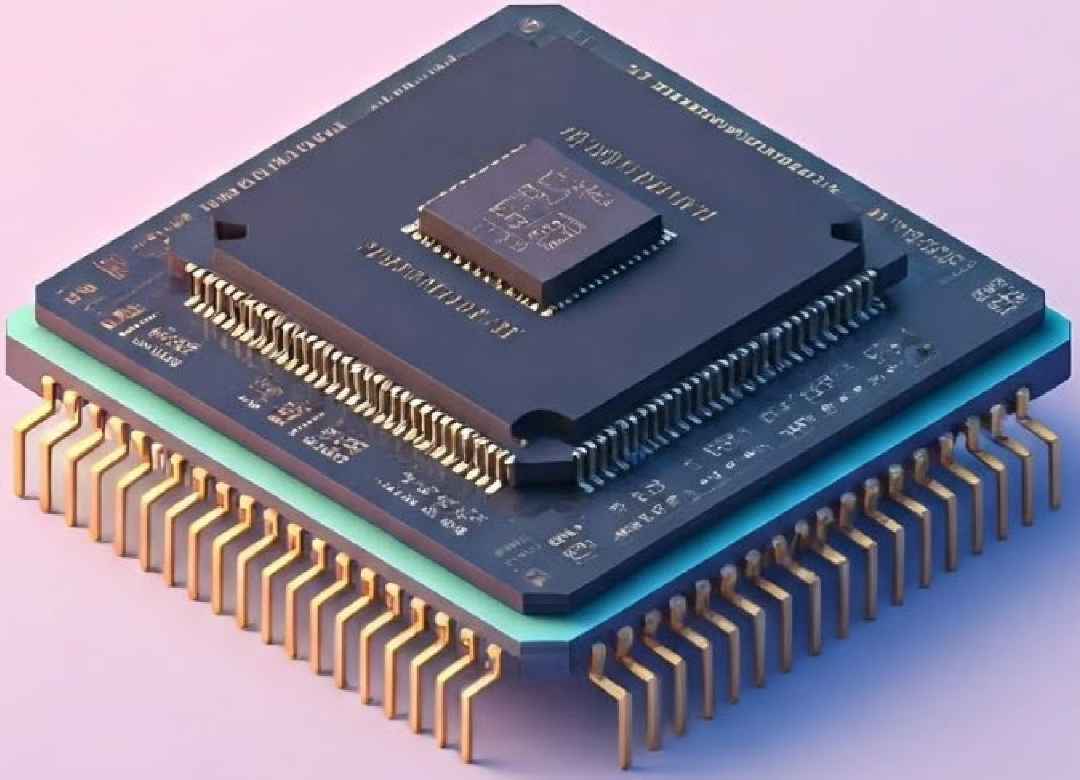
27th – 31st October 2024

Sawal Hamid Md Ali
Universiti Kebangsaan Malaysia (UKM)
31/10/2024

Universiti Kebangsaan Malaysia
The National University of Malaysia

Who has worked with microcontrollers? Arduino? Microprocessors? Rpi? FPGA? SoC?

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.

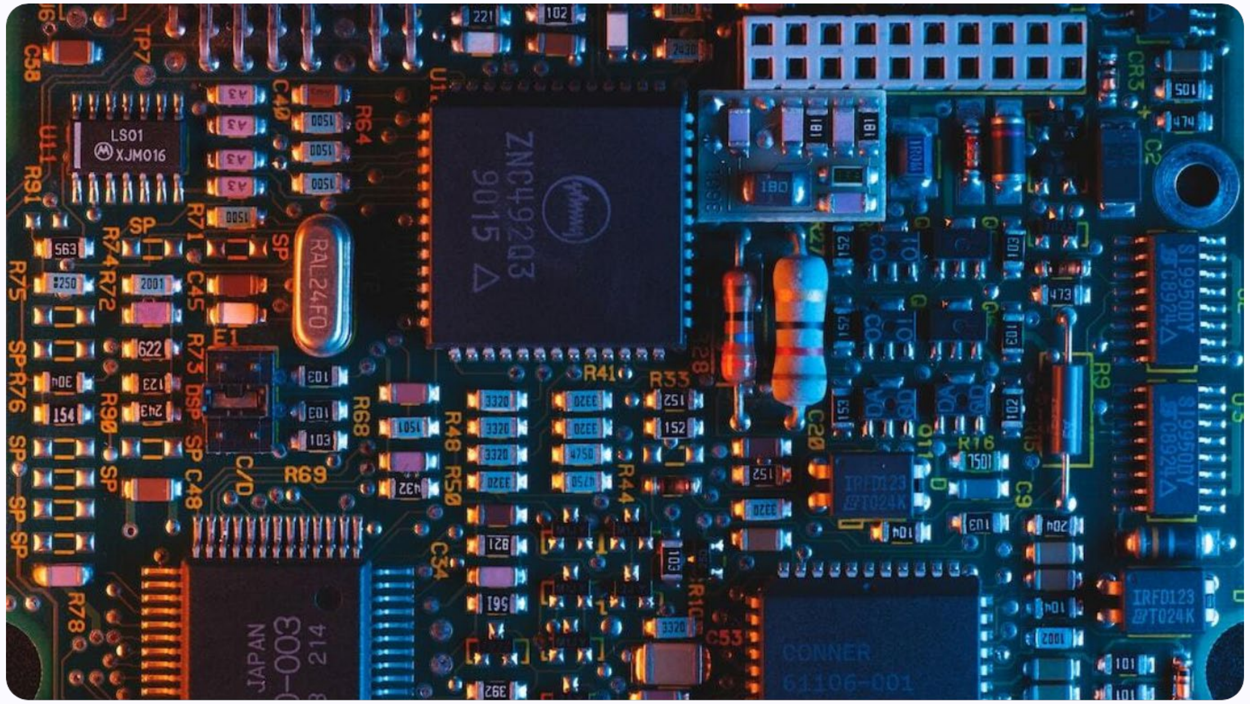
3 Efficiency

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

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

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.



Why do you need FPGA? PSoC?

Programmable SoC (PSoC)

1 Evolution

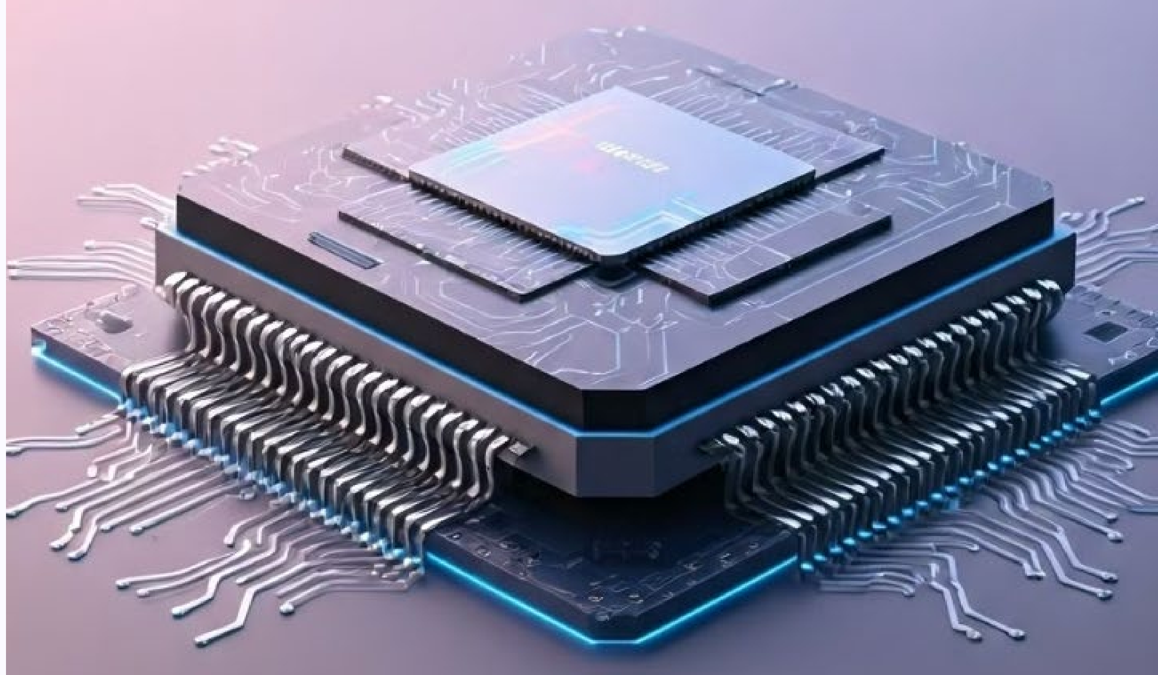
PSoCs emerged as a solution to combine the flexibility of FPGAs with SoC efficiency.

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.



Universiti Kebangsaan Malaysia
The National University of Malaysia

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.

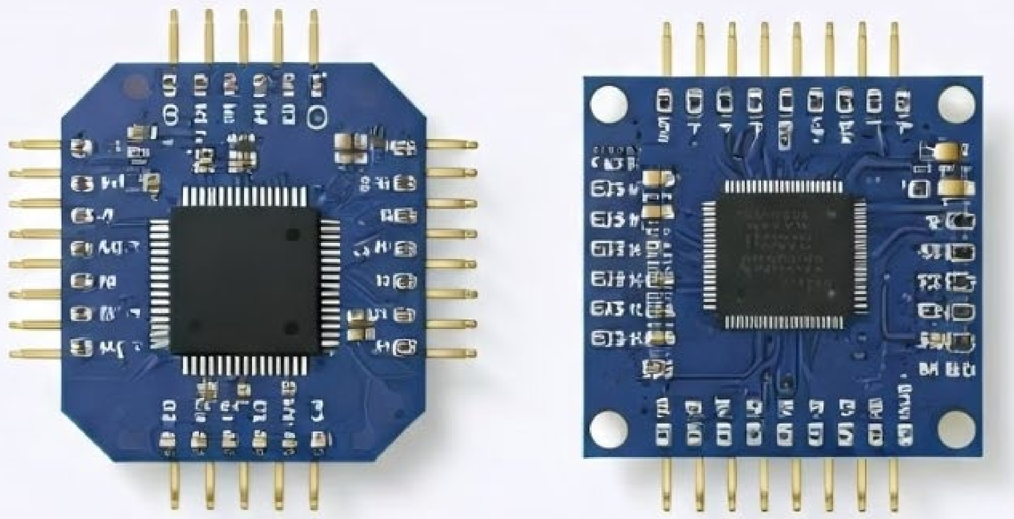
Peripherals

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

Universiti Kebangsaan Malaysia
The National University of Malaysia

Comparison of PSoC, Microprocessors, and Microcontrollers

Feature	PSoC	Microprocessor	Microcontroller
Cost	Lower cost	Higher cost	Moderate cost
Power Consumption	Lower power consumption	Higher power consumption	Moderate 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



Universiti Kebangsaan Malaysia
The National University of Malaysia

Flexibility and Customization

Adaptability

PSoCs can be reconfigured on-the-fly, adapting to changing requirements without hardware modifications.

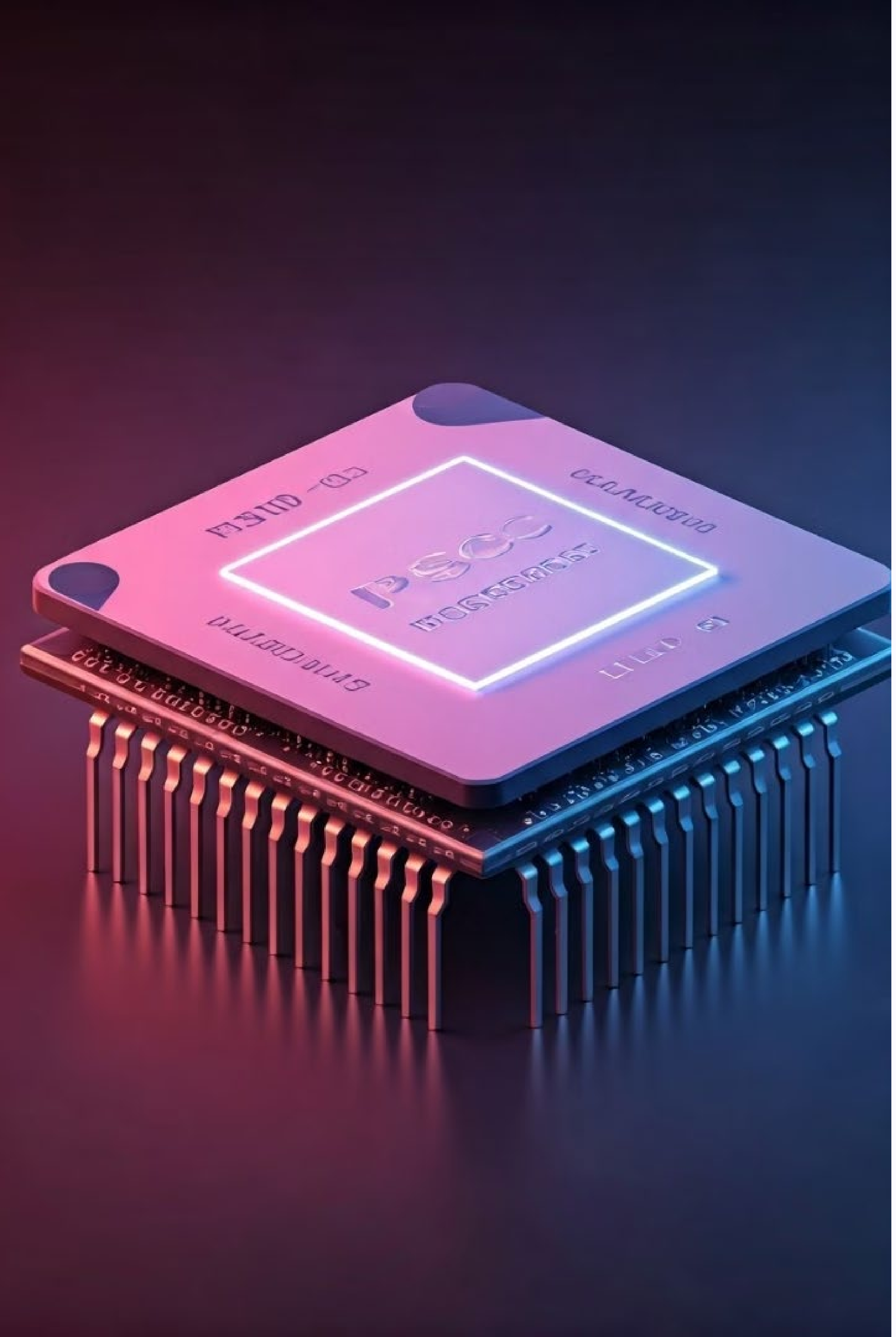
Resource Optimization

Designers can allocate hardware resources efficiently, tailoring the system to specific application needs.

Innovation

The flexibility of PSoCs enables rapid prototyping and implementation of novel ideas.

Universiti Kebangsaan Malaysia
The National University of Malaysia



Power Efficiency

1 Dynamic Power Management

PSoCs can selectively power down unused components, significantly reducing overall power consumption.

2 Optimized Architectures

Custom hardware implementations often require fewer clock cycles, leading to improved energy efficiency.

3 Voltage Scaling

PSoCs support fine-grained voltage control, allowing for optimal performance-power trade-offs.

Universiti Kebangsaan Malaysia
The National University of Malaysia

Faster Time to Market

1 **Rapid Prototyping**

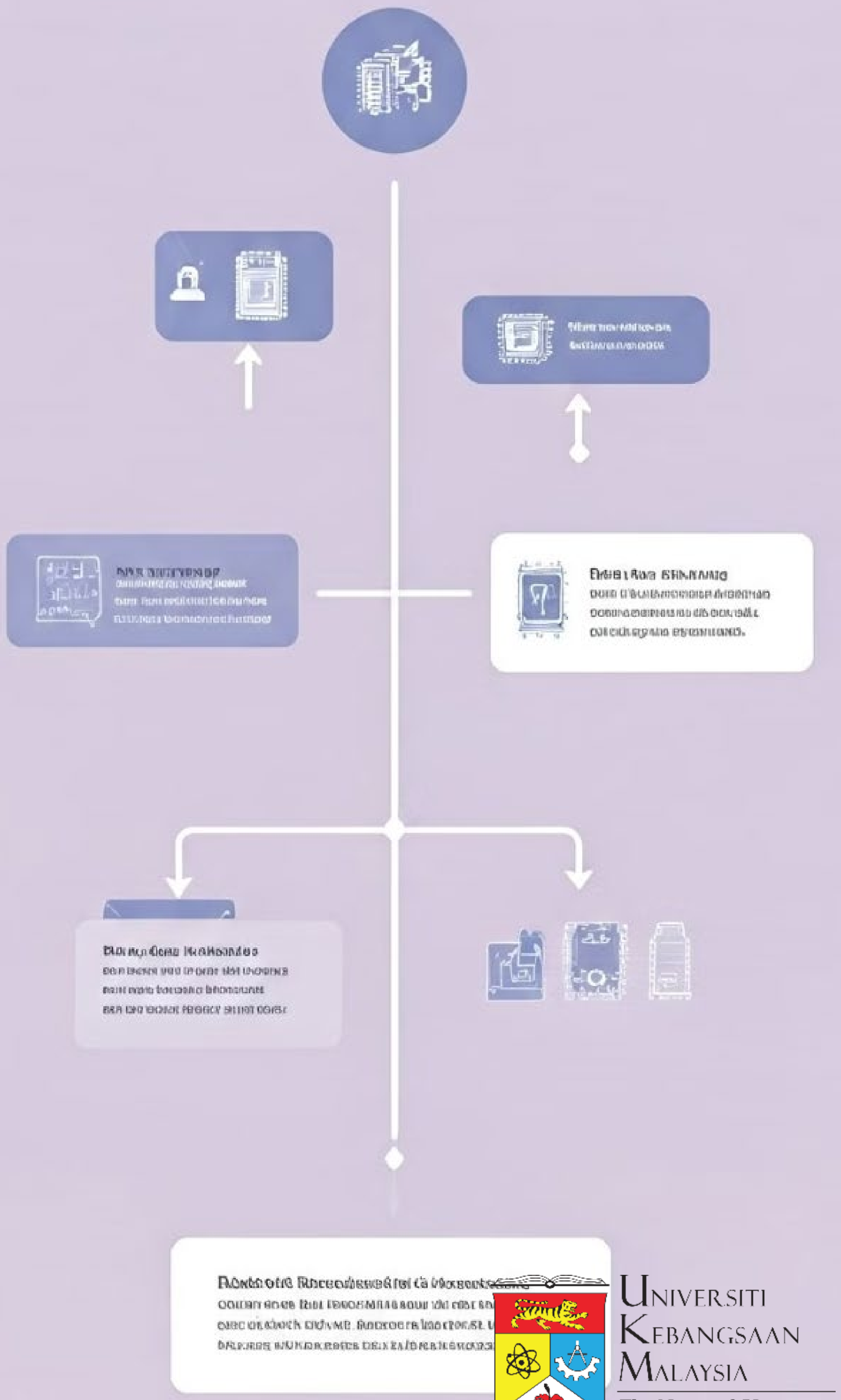
PSoCs enable quick hardware iterations, accelerating the design validation process.

2 **Software/Hardware Co-design**

Simultaneous development of hardware and software reduces overall development time.

3 **Reusability**

Pre-designed IP blocks and modular architecture allow for faster system integration.



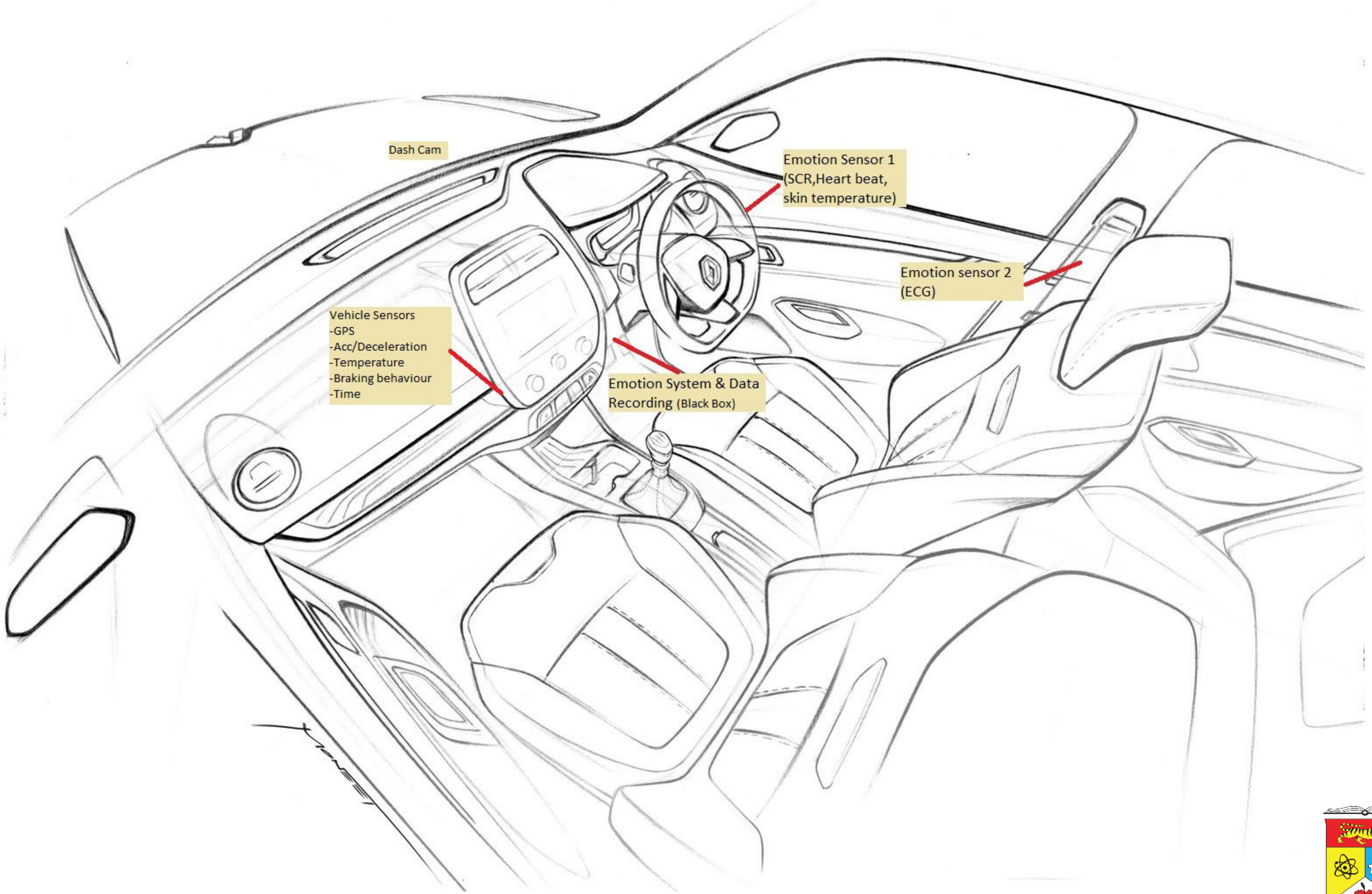
Universiti Kebangsaan Malaysia
The National University of Malaysia

Case Study 1 :
Human Emotion Detection

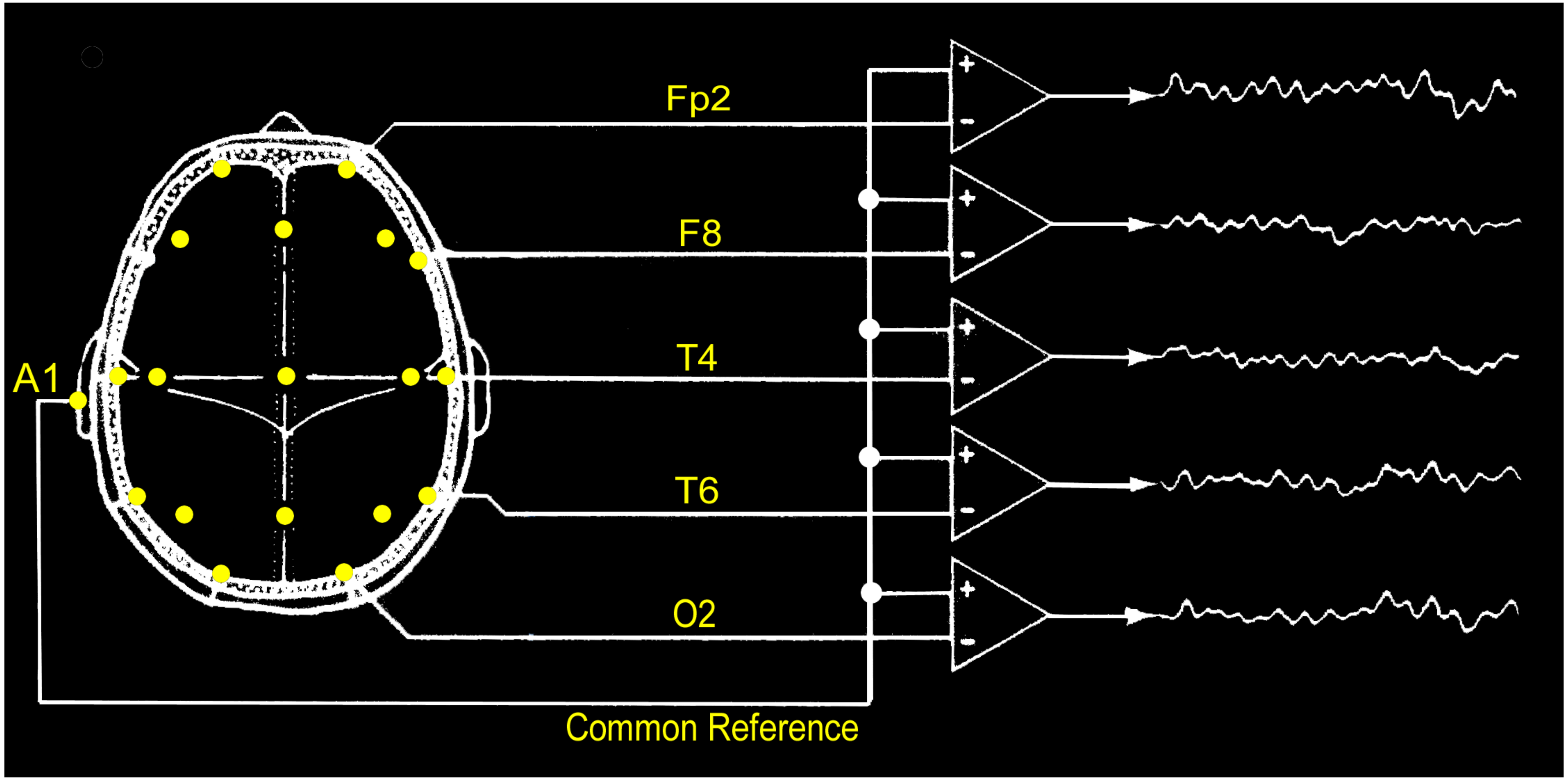
- In-Lab experiment (Audio Visual stimuli)
- Simulator based experiment (Driving game)

Universiti Kebangsaan Malaysia
The National University of Malaysia

Proposed Prototype (patented)



Universiti Kebangsaan Malaysia
The National University of Malaysia



Universiti Kebangsaan Malaysia
The National University of Malaysia

Human Emotion Recognition Experiment

Number of subjects

10 subjects (male and female)

Stimuli

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

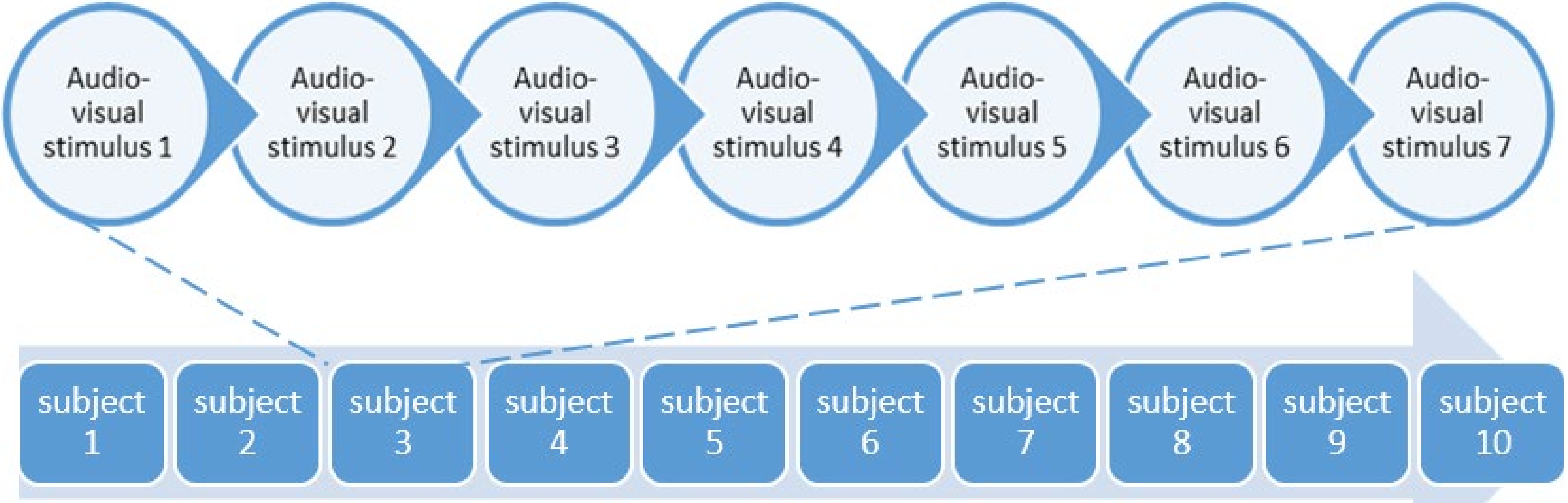
Number of emotions

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

Universiti Kebangsaan Malaysia
The National University of Malaysia



Universiti Kebangsaan Malaysia
The National University of Malaysia

Case Study 2: Using PSoC for Neuroprosthetic Applications

Overview of Neuroprosthetics 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.

Universiti Kebangsaan Malaysia
The National University of Malaysia

Challenges in Neuroprosthetic Design and Implementation

Signal Processing

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

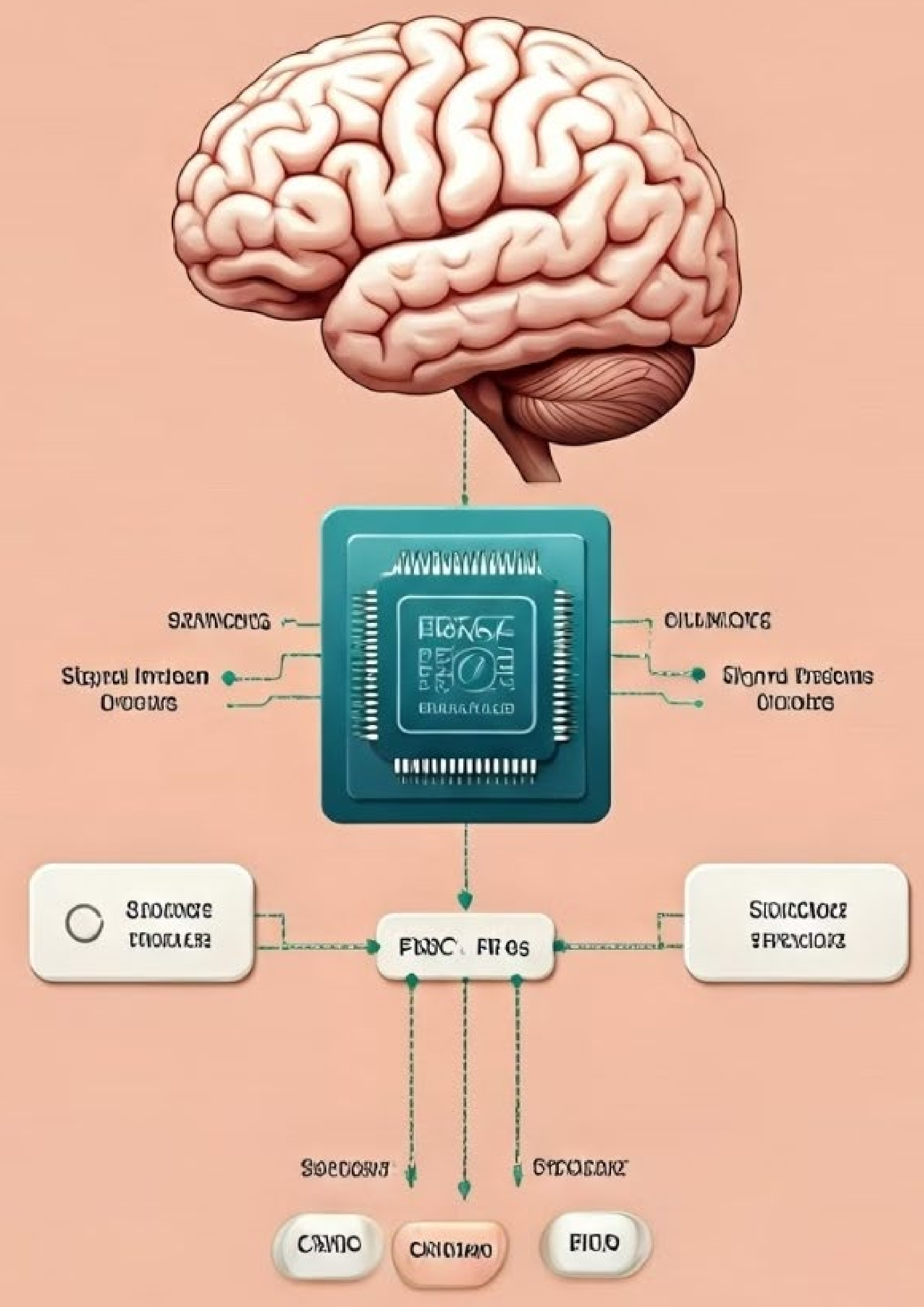
Power Consumption

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.

Universiti Kebangsaan Malaysia
The National University of Malaysia



Integrating FPGA Capabilities in in PSoC for Neuroprosthetics

1
Signal Acquisition

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

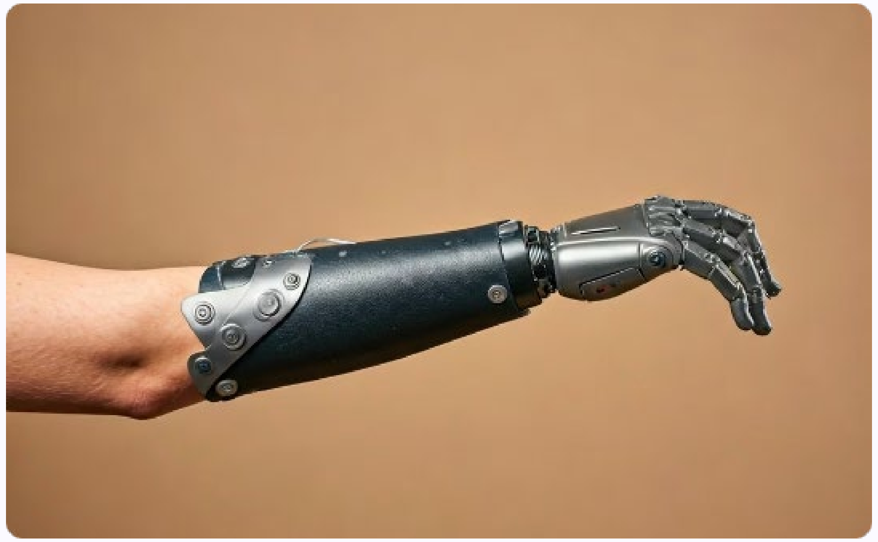
2
Signal Processing

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.

Real-World Examples of PSoC-based Neuroprosthetic Devices

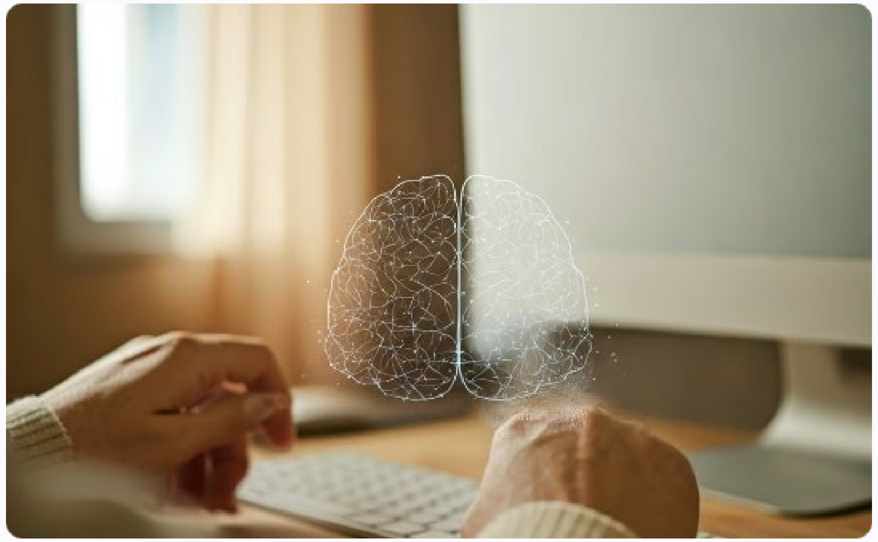


Prosthetic Arms

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

Prosthetic Legs

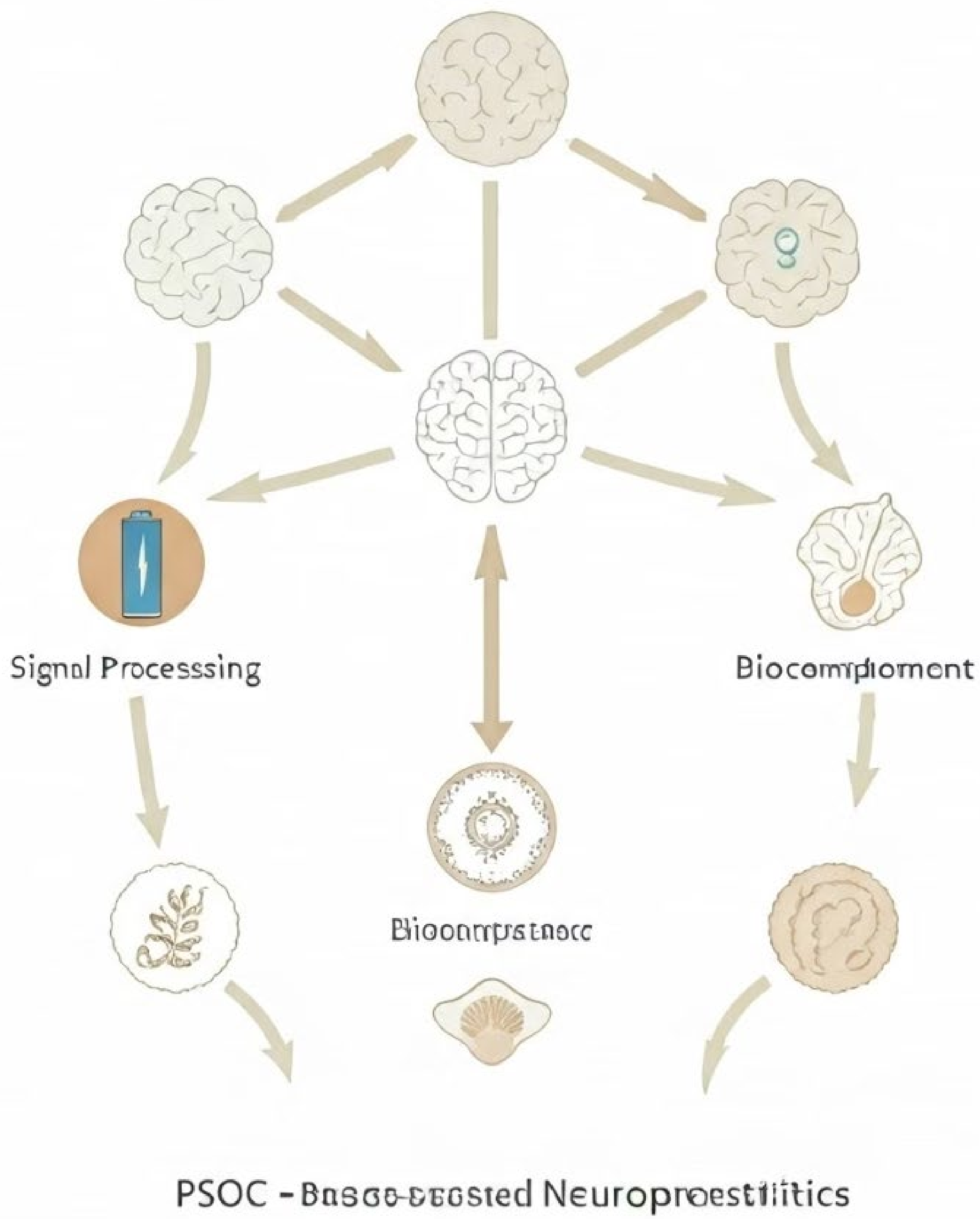
PSoC facilitates precise control of prosthetic legs, providing a smooth and responsive walking experience.



Brain-Computer Interfaces

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

Universiti Kebangsaan Malaysia
The National University of Malaysia



Key Design Considerations for PSoC-based PSoC-based Neuroprosthetics

1

Signal Processing

Choose the right algorithms and techniques to accurately extract and interpret neural signals.

2

Power Management

Optimize power consumption to ensure long battery life and device portability.

3

Biocompatibility

Ensure the device materials and design are safe and compatible with the biological environment.

4

User Interface

Design an intuitive and user-friendly interface that enables seamless interaction with the device.

Universiti Kebangsaan Malaysia
The National University of Malaysia

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)

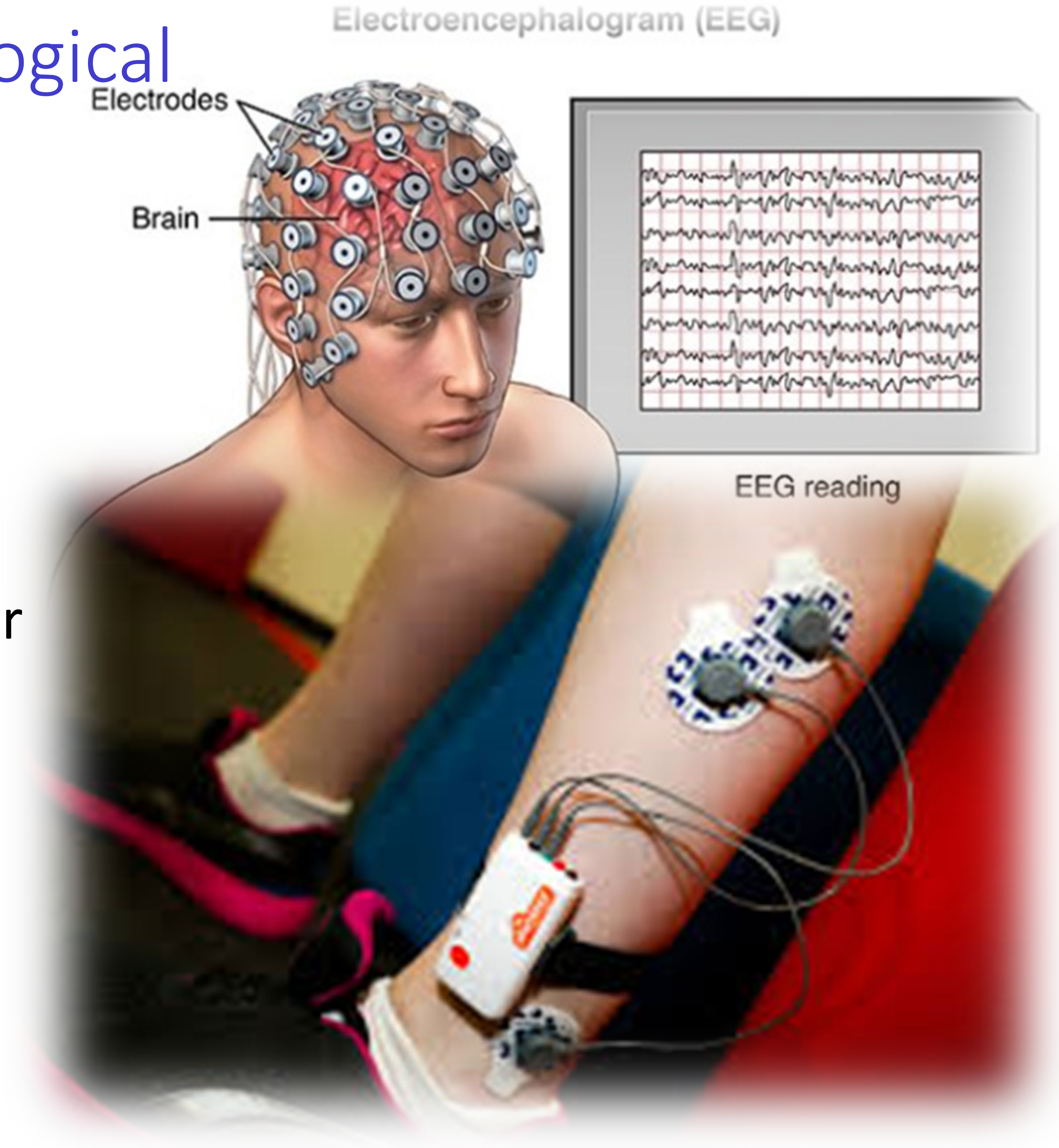
UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

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

Universiti Kebangsaan Malaysia
The National University of Malaysia

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.

Universiti Kebangsaan Malaysia
The National University of Malaysia

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.

Universiti Kebangsaan Malaysia
The National University of Malaysia

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.

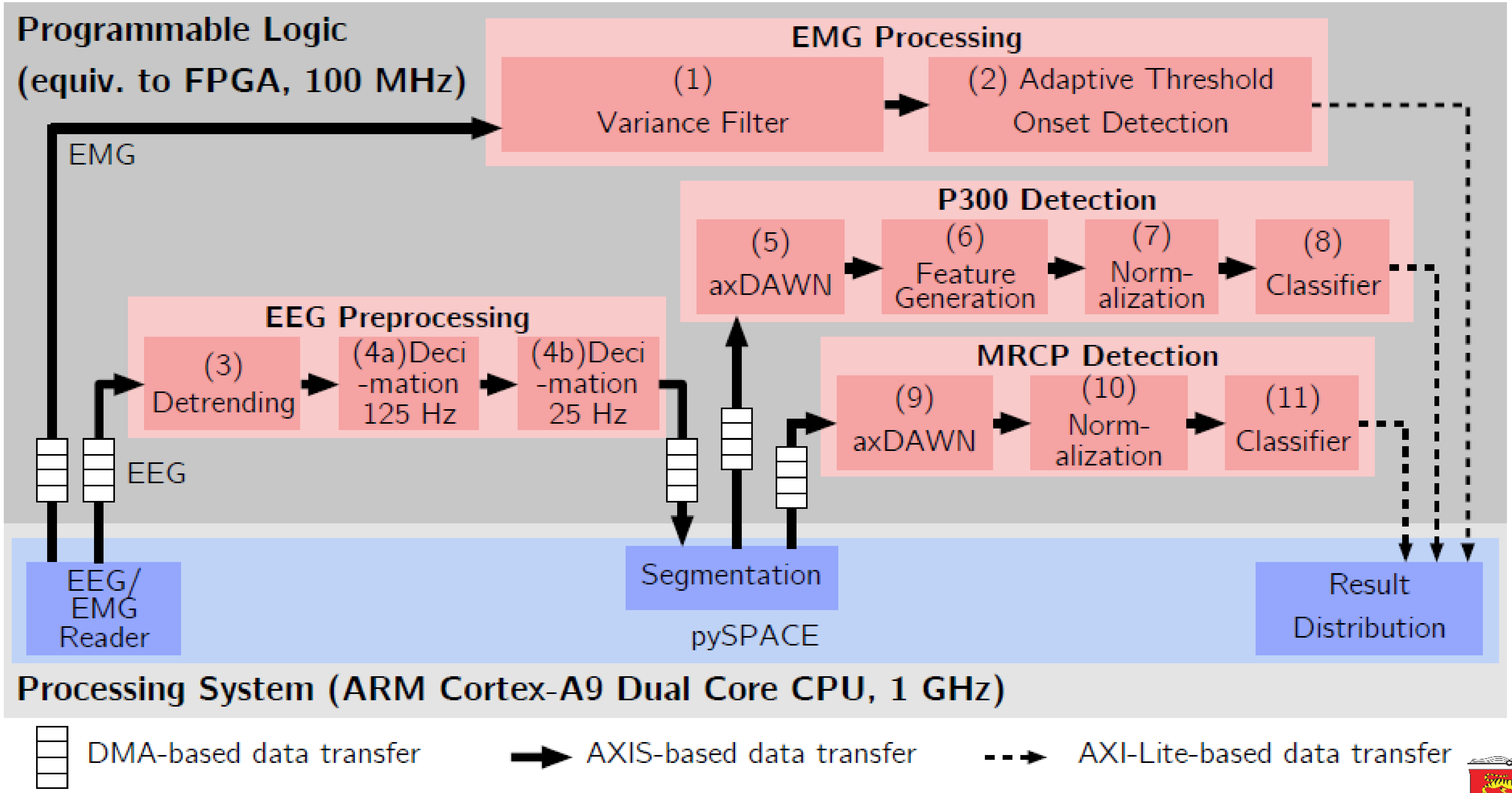
EMG measures electric potentials generated by active muscles

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

Universiti Kebangsaan Malaysia
The National University of Malaysia

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**

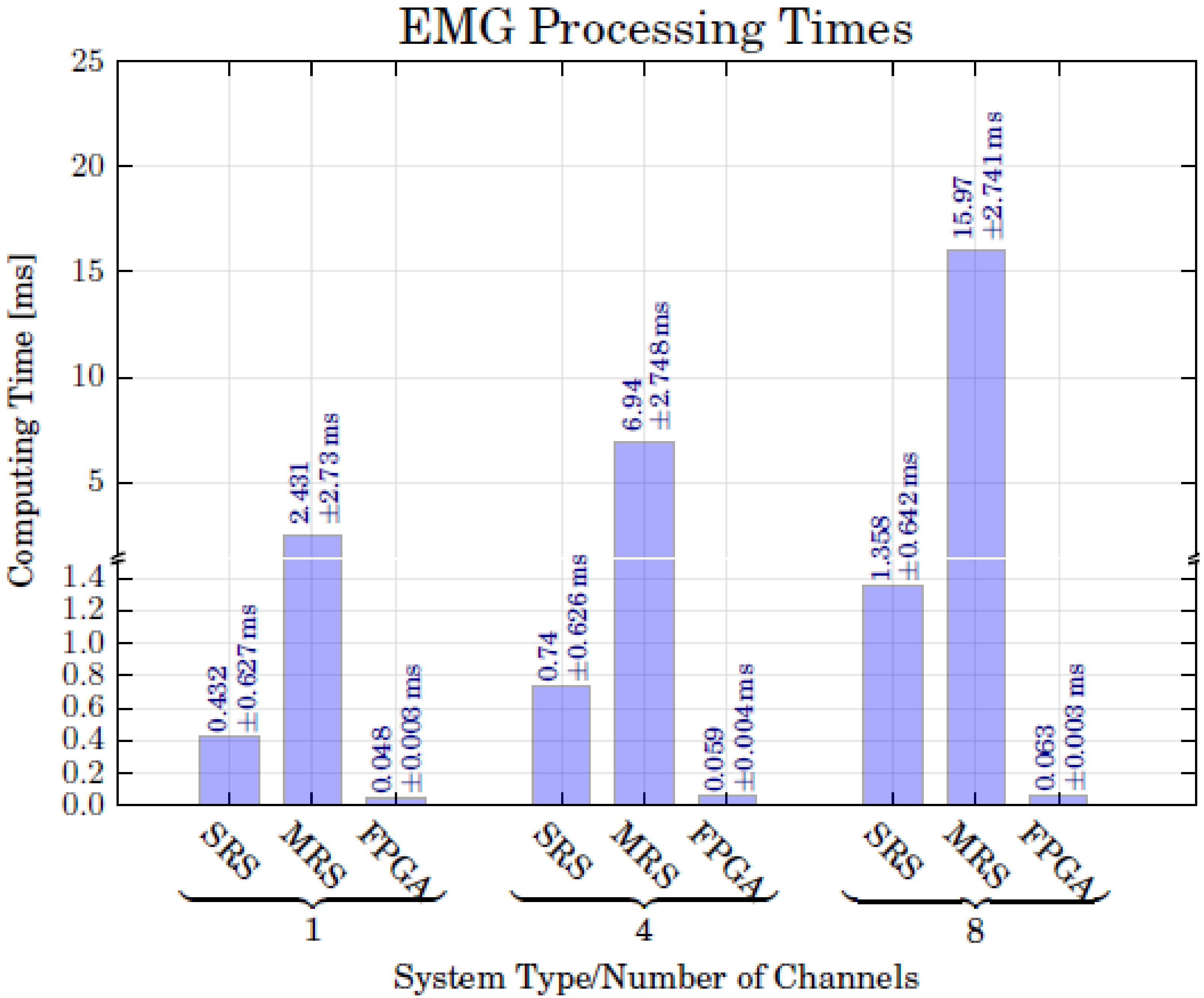
PSoC system for upcoming moving prediction



Universiti Kebangsaan Malaysia
The National University of Malaysia

Cited from [1]

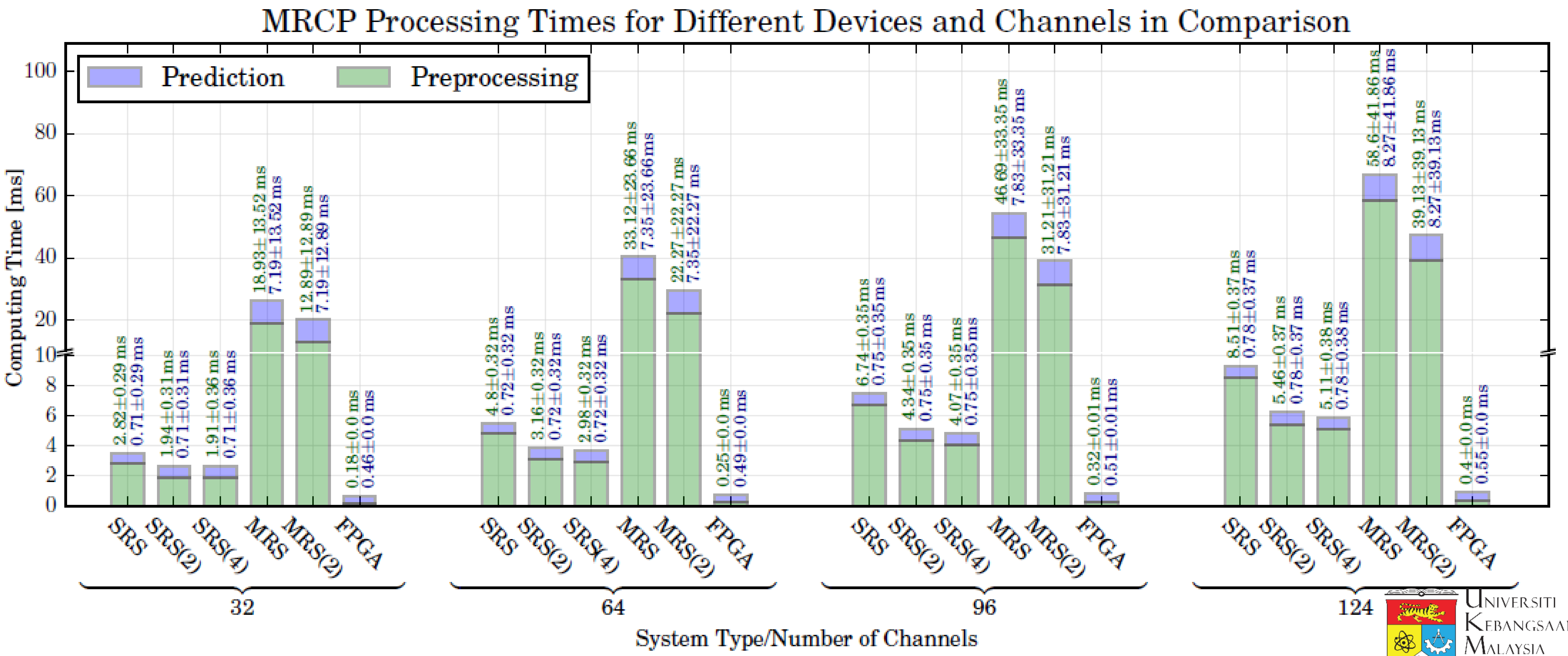
Processing time comparison (CPU vs FPGA) - EMG



Cited from [1]

Universiti Kebangsaan Malaysia
The National University of Malaysia

Processing time comparison (CPU vs FPGA) - EEG



Cited from [1]

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		

Cited from [1]

Conclusion and Future Trends in PSoC for Healthcare Systems

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

Sawal Hamid Md Ali
Department of Electrical, Electronic and Systems Engineering
Faculty of Engineering and Built Envrionment
University Kebangsaan Malaysia

sawal@ukm.edu.my
+6012-2592475

Universiti Kebangsaan Malaysia
The National University of Malaysia