Human-centred Research at the Óbuda University

Signals, intelligent systems and assistive technologies designed around people

Biomechatronics Research Group
Réka Sallay, Dr. Arnold Őszi

2026

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Presentation overview

Presentation progress

A human-centred question

- How can technology understand the human body?
  - Can a computer recognise a person from brain activity?
  - Can a prosthetic hand respond naturally to muscle intention?
  - Can technology adapt to the user instead of forcing the user to adapt?
- Our research begins with the person, not with the device.

What does "human-centred" mean?

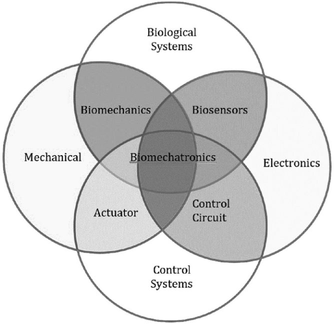
- Human-centred research considers:
  - human capabilities / limitations;
  - comfort and fatigue;
  - individual differences;
  - safety, reliability, accessibility;
  - the context in which technology is used.
- The central question:
  - Does the technology fit the person and their real needs?

Ergonomics beyond chairs and workplaces

- Ergonomics is often associated with posture or workplace design.
- However, ergonomics also includes:
  - cognitive workload;
  - physical effort;
  - interaction with machines;
  - accessibility;
  - emotional acceptance;
  - system usability;
  - adaptation to individual users.
- In biomechatronics, ergonomics connects the human body, the human nervous system and the engineered system.

The Biomechatronics Research Group

- We work at the intersection of:
  - biomedical engineering;
  - signal processing;
  - neuroscience;
  - artificial intelligence;
  - control engineering;
  - robotics;
  - human-machine interaction.
- Our objective is to observe human physiological activity, interpret measured signals and respond in a useful, human-compatible way.

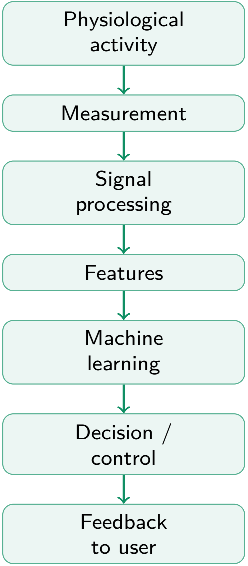


Our main research directions

- Signals
  - Electroencephalography – EEG
  - Electromyography – EMG
  - Other physiological and biomedical signals
- Intelligence
  - Neural networks
  - Dynamical neural and synaptic models
- Applications
  - Biometrics, prosthetic control, assistive technologies, human-state monitoring

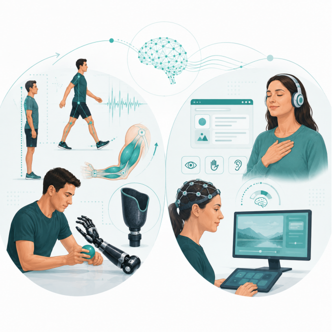
The research cycle

- From the human body to an intelligent response:
  - physiological activity;
  - measurement;
  - signal processing;
  - feature extraction;
  - machine learning;
  - decision or control;
  - feedback to the user.
- The system is not complete when it produces an output.
- The output must also be understandable, reliable and useful for the person.



Biomedical signals

- Biomedical signals are measurements generated by physiological processes.
- Examples include:
  - electrical brain activity;
  - electrical muscle activity;
  - heart activity.
- What makes these signals difficult?
  - They are often weak, noisy, variable, affected by movement and different across people and recording sessions.



Signal analysis: separating information from noise

- A measured signal contains more than the activity we want to study.
- It may also contain electrical interference, movement artefacts, electrode displacement, eye movements, muscle activity, changes in skin contact and environmental noise.
- A typical processing pipeline:

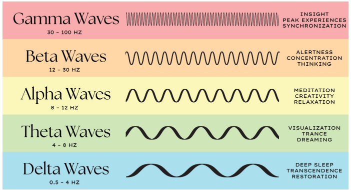
  Raw signal $\rightarrow$ **filtering** $\rightarrow$ **segmentation** $\rightarrow$ **features** $\rightarrow$ **classification**

- Good artificial intelligence cannot compensate for poor measurement quality.

Presentation progress

EEG: listening to brain activity

- Electroencephalography, or EEG, measures electrical activity from the scalp.
- EEG is non-invasive, relatively affordable, temporally precise and sensitive to mental and physiological states.
- EEG signals are affected by attention, fatigue, emotional state, eye movements, electrode placement and recording conditions.



Can brain activity identify a person?

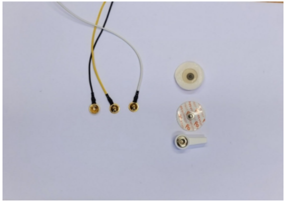
- Traditional biometric characteristics include fingerprints, facial images, iris patterns, voice and signatures.
- EEG-based biometrics asks:
  - Does each person have sufficiently distinctive patterns of brain activity to support recognition?
- The idea is attractive because EEG signals are generated internally, difficult to observe remotely and related to both anatomy and neural function.

Identification and verification

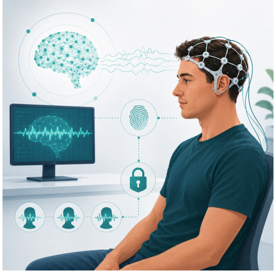
- Identification
  - "Who is this person?"
  - The system compares the signal with several registered users.
- Verification
  - "Is this person really the claimed user?"
  - The system compares the signal with the claimed identity.
- A system can perform well in a controlled laboratory and still be uncomfortable or unreliable in real use.

A typical EEG biometric experiment

- Place EEG electrodes on the participant.
- Record brain activity during a defined task.
- Remove artefacts and noisy segments.
- Divide the signal into shorter windows.
- Extract informative characteristics.
- Train a classification model and test it on unseen recordings.
- Possible tasks: resting eyes open/closed, viewing visual stimuli, imagined movement and cognitive tasks.



What are we actually recognising?



- An EEG biometric model may learn a combination of:
  - anatomical differences;
  - stable neural patterns;
  - responses to a stimulus;
  - recording-session characteristics;
  - electrode placement;
  - device-related artefacts.
- Therefore, a strong result must answer:
  - Does the system recognise the person?
  - Or does it recognise the recording conditions?
- This is why experimental design is as important as model accuracy.

The main challenges of EEG biometrics

- Variability: EEG changes over time, even for the same person.
- Usability: traditional EEG systems may require many electrodes, conductive gel, careful preparation and expert placement.
- Robustness: the system should tolerate different days, mental states, electrode shifts and realistic environmental noise.
- Ethics and privacy: brain signals may reveal information beyond identity.

Human-centred evaluation of EEG biometrics

- A useful biometric system should be accurate, quick to set up, comfortable, understandable, privacy-preserving, robust across sessions and inclusive of different users.
- Accuracy is only one dimension.
- A system with 99% laboratory accuracy may still be unusable if preparation takes 30 minutes.

Neural networks in biometrics

- Neural networks can learn complex patterns directly from biomedical signals.
- They can be used for feature extraction, classification, representation learning, anomaly detection and multimodal data fusion.
- Common limitation: large neural networks may require extensive training data, high computational power, significant energy consumption and careful interpretation.
- Human-centred engineering must also consider the cost and transparency of intelligence.

Presentation progress

From artificial neurons to spiking neurons

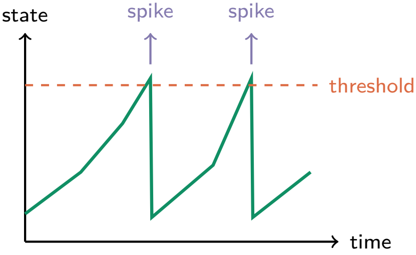
- Most conventional neural networks exchange continuous numerical values.
- Biological neurons communicate using short electrical events called spikes.
- Spiking neural networks represent information through:
  - the presence of spikes;
  - spike frequency;
  - spike timing;
  - temporal patterns.
- They combine neural-network computation with biologically inspired dynamics.

Why use spiking neural networks?

- Potential advantages include natural representation of time, event-driven computation, compatibility with neuromorphic hardware, potentially lower energy consumption and closer connection to biological models.
- Why this matters for biomedical signals:
  - EEG and EMG are fundamentally time-dependent.
  - A model should not only ask: "What is the signal value?"
  - It should also ask: "When did the event occur?"

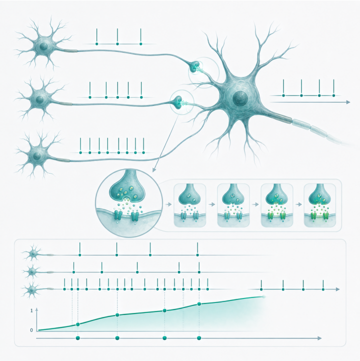
A simplified spiking-neuron model

- A spiking neuron receives input over time.
- Its internal state gradually changes.
- When the state reaches a threshold:
  - the neuron produces a spike;
  - the state is reset;
  - the spike is transmitted to connected neurons.
- Information is distributed across both network structure and temporal dynamics.
- This creates new possibilities, but also new training and interpretation challenges.



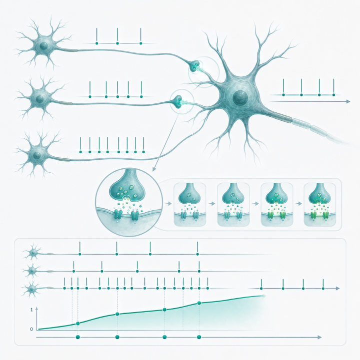
Dynamical synapse modelling

- A synapse is the connection through which one neuron influences another.
- In simple neural networks, a connection is represented by a fixed weight.
- Biological synapses are not fixed.
- Their effect may depend on recent activity, spike timing, neurotransmitter dynamics, adaptation, facilitation, depression and learning history.
- A dynamical synapse changes its response as a function of time and activity.



Why model synaptic dynamics?

- Dynamical synapse models can help us study short-term memory, adaptation, temporal filtering, learning, biological plausibility and efficient information transmission.
- Engineering perspective:
  - A dynamic connection can behave differently depending on context.
- This may allow artificial systems to become more adaptive, efficient and responsive to changing signal conditions.



Presentation progress

EMG: measuring muscle intention

- Electromyography, or EMG, measures electrical activity associated with muscle activation.
- When a person intends to move:
  - the nervous system sends commands to the muscles;
  - muscle fibres become electrically active;
  - electrodes measure part of this activity;
  - the signal is processed;
  - the intended movement is estimated.
- EMG creates a direct link between human intention and machine control.

EMG-controlled prosthetics

- A myoelectric prosthesis uses EMG signals to control an artificial limb.
- Simplified control chain:

  Muscle activation → EMG measurement → movement recognition → prosthetic action

- Possible commands include opening or closing the hand, changing grip type, rotating the wrist and controlling individual fingers.
- The technical goal is not simply movement. The goal is movement that feels predictable and useful to the user.

Why prosthetic control is difficult

- EMG signals depend on electrode position, skin condition, muscle fatigue, arm posture, socket pressure, movement speed and day-to-day variation.
- A model trained in one posture may perform poorly in another.
- Human-centred challenge:
  - The user should not have to repeat an exact laboratory posture every time they want to use the prosthesis.

The ergonomics of a prosthetic system

Physical factors

- weight
- socket comfort
- heat and pressure
- fatigue
- range of motion

Cognitive factors

- concentration required
- number of commands
- predictability
- error recovery
- learning time

Social factors

- appearance
- confidence
- acceptance
- use in public environments

A prosthesis should be evaluated as a complete human-machine system.

Accuracy is not the same as usability

System A

- 95% classification accuracy;
- requires strong, repeated muscle contractions;
- takes several seconds to respond.

System B

- 90% classification accuracy;
- responds quickly;
- requires little effort;
- errors are easy to correct.

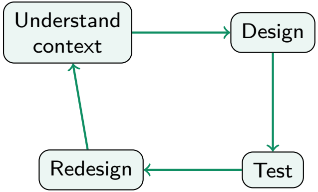
Which system is better for the user?

The answer depends on the task, the user and the cost of an error.

Presentation progress

Human-in-the-loop design

- A human-centred system is developed iteratively.
- Understand the user and the context.
- Design an initial solution.
- Test it with users.
- Measure technical and human factors.
- Identify problems.
- Redesign the system.
- Test again.
- Users are not simply test subjects; they are sources of design knowledge.



What should we measure?

Technical performance

- accuracy
- sensitivity / specificity
- false acceptance / rejection
- response time
- computational cost
- robustness

Human performance

- task-completion time
- physical effort
- mental workload
- learning rate
- comfort
- confidence

User experience

- satisfaction
- trust
- perceived control
- willingness to use the system

Trust in intelligent biomedical systems

- Users may ask:
  - Why did the system make this decision?
  - What happens when it is wrong?
  - Can I override it?
  - Who has access to my data?
  - Will it work tomorrow?
  - Does it work equally well for everyone?
- Trust is created through consistent behaviour, understandable feedback, transparent limitations, safe error handling and respect for user data.

Ethical questions

- Human-centred biomedical research must consider informed consent, privacy, data ownership, security, fairness, accessibility, potential misuse and long-term effects.
- Example:
    - An EEG recording collected for identity recognition may also contain information related to fatigue, attention, stress or neurological conditions.
- Researchers must clearly define what is collected and how it may be used.

Inclusive research

- Biomedical models may perform differently across users.
- Differences may be related to age, anatomy, health condition, mobility, skin properties, previous experience and cognitive or physical ability.
- Inclusive design asks:
  - Who participated in the study?
  - Who was excluded?
  - Who benefits from the system?
  - For whom might the system fail?

Bringing the research areas together

- EEG biometrics: understanding identity through brain activity.
- Spiking neural networks: processing temporal information using event-based computation.
- Dynamical synapses: modelling adaptation and changing neural connections.
- EMG prosthetics: transforming muscle activity into assistive movement.
- Shared principle: measure the human carefully, interpret the signal responsibly and design the response around the user.

An integrated future system

- Imagine a personalised assistive device that learns the user's physiological patterns, adapts to fatigue and changing conditions, processes signals efficiently, recognises uncertainty, asks for confirmation when needed, explains its actions and protects personal data.
- This requires more than artificial intelligence.
- It requires engineering, neuroscience, ergonomics, ethics and continuous user involvement.

Presentation progress

How students can participate

- Possible student projects include recording EEG or EMG measurements, comparing machine-learning models, implementing existing spiking neural networks, developing visualisation tools, building experimental interfaces, studying comfort and workload and designing user experiments.
- Relevant backgrounds: engineering, computer science, neuroscience, mathematics, medicine, physics.

What research work actually looks like

- Research is not a straight line.
- It involves: reading, designing experiments, building prototypes, collecting data, debugging, analysing unexpected results, questioning assumptions, repeating measurements and communicating findings.
- An unexpected result is not always a failure.
- It may reveal that our original model of the problem was incomplete.

Final thought

- The most advanced technology is not necessarily the technology with the largest model or the highest laboratory accuracy.
- The most meaningful technology is the technology that:
    - understands human variability;
    - supports human capabilities;
    - respects human limitations;
    - improves human experience.
- Human-centred research transforms technical possibilities into useful solutions.

Thank you for your kind attention!