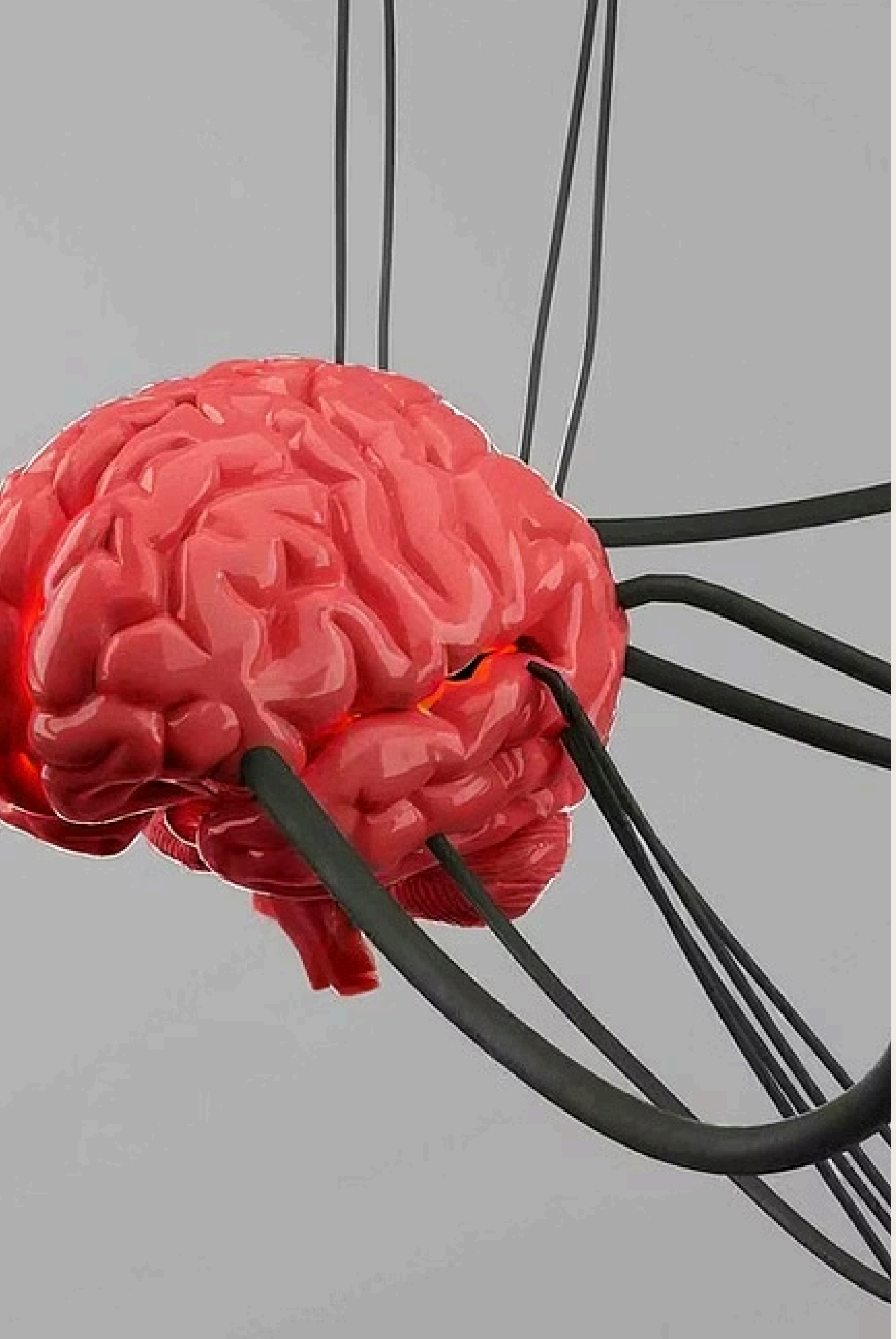
Brain–Computer Interfaces in Robotics

Direct neural control of robotic systems

Ahmed Mehdi SOLTANI

Rendra Anughrah Budiputra DJUNAEDI

Made with GAMMA



What is a Brain–Computer Interface?

Direct Neural Interface

Brain to machine communication

Unidirectional

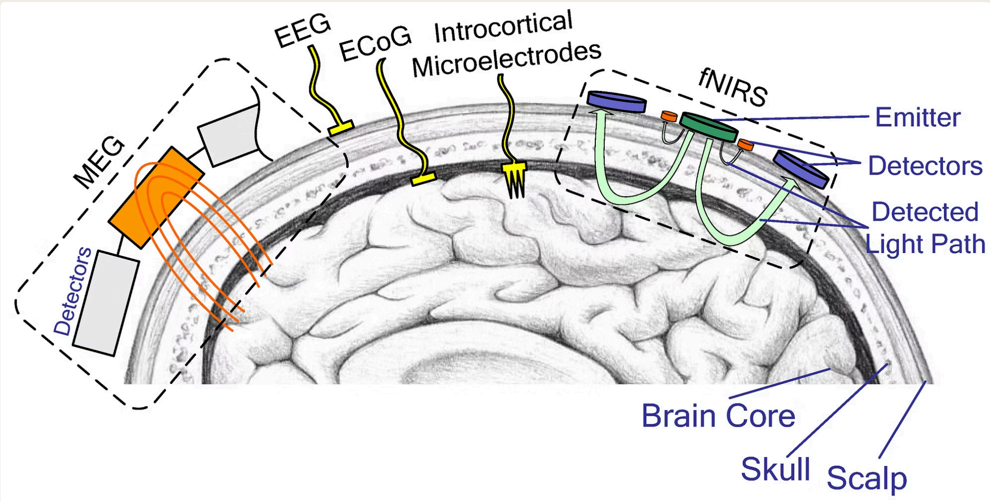
Brain - > machine signals

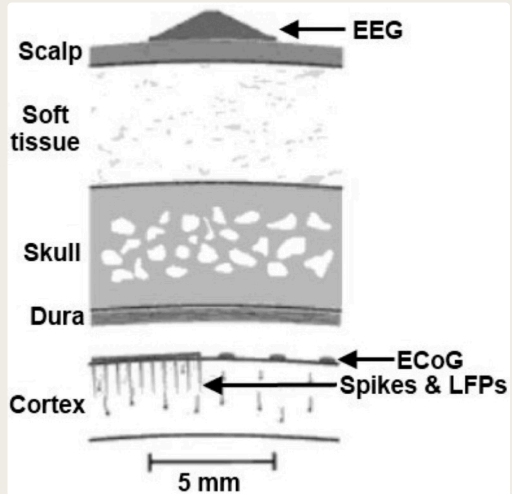
Bidirectional

Brain < - > machine feedback

Made with GAMMA

BCI Modalities: Invasive vs Non-Invasive





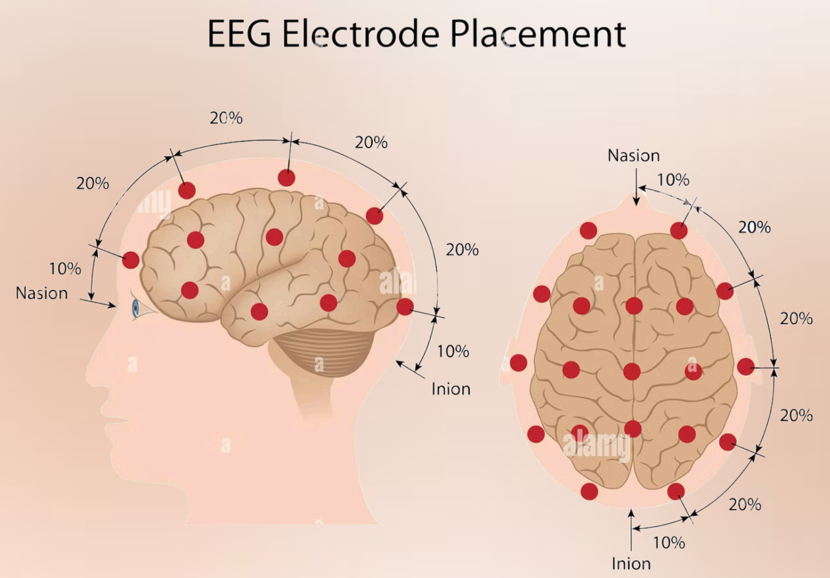
Non-Invasive

- EEG: scalp electrodes, fast but noisy
- MEG: magnetic fields, precise but costly
- fNIRS: blood flow, slow response

Invasive

- ECoG: cortex electrodes, precise
- Higher spatial resolution
- Surgical risks involved

Made with GAMMA



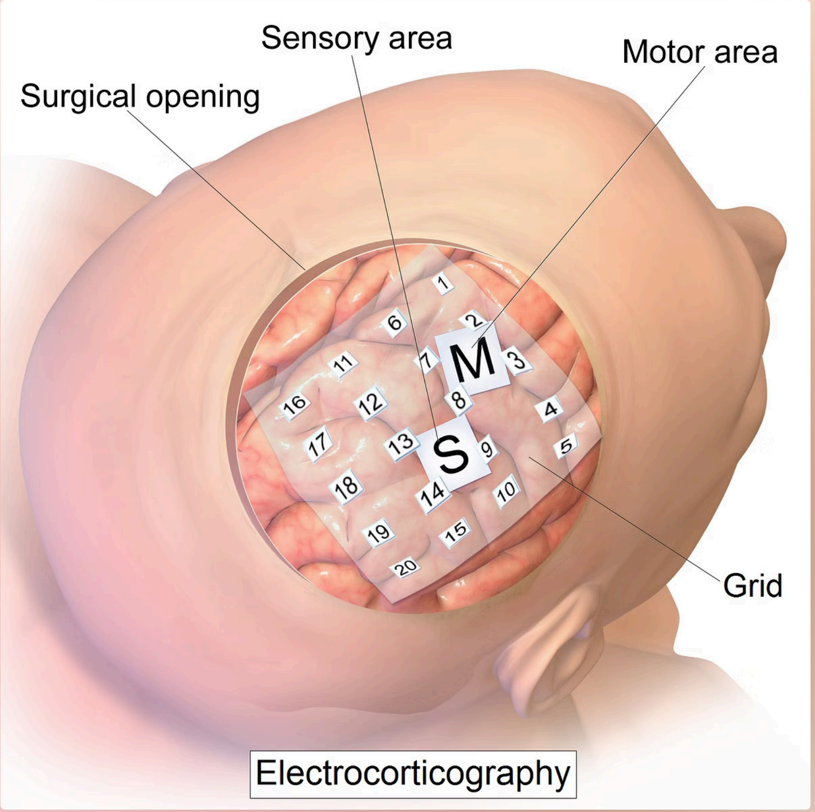
EEG (Electroencephalography) Sensors

EEG sensors detect voltage fluctuations caused by ionic current flows within neurons in the brain

Main Components:

- Electrodes
- Amplifier
- Filters
- Analog-to-Digital Converter
- Signal Processing Unit

Made with GAMMA



ECoG (Electrocorticography) Sensors

ECoG electrodes detect electrical activity directly from the brain's cortical surface, providing much higher spatial resolution and signal quality than EEG.

Main Components:

- Subdural Electrodes
- Electrode Grid or Strip
- Microelectrodes (Optional in some systems)
- Amplifier
- Filters
- Connector and External Processor

Made with GAMMA

Complete BCI Pipeline

1. **Signal Acquisition**
   Neural data capture
2. **Preprocessing**
   Amplify & filter
3. **Feature Extraction**
   Measurable properties
4. **Classification**
   ML algorithms decode
5. **Command Mapping**
   Intention → action
6. **Robot Control**
   Execute movement

Made with GAMMA

Signal Acquisition & Preprocessing

Capture

Brain activity acquisition

Amplify

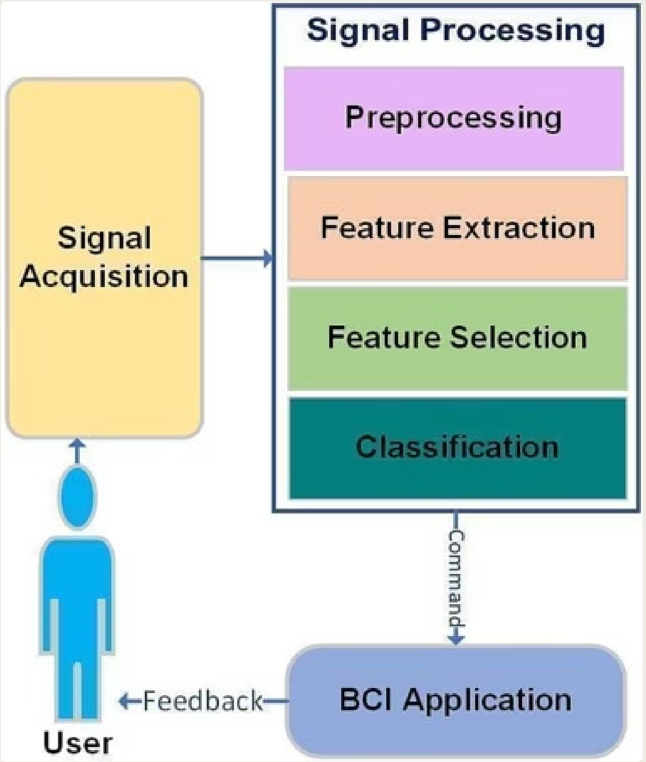
Signal enhancement

Filter

Noise removal

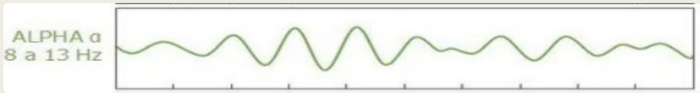
Clean

Artifact elimination



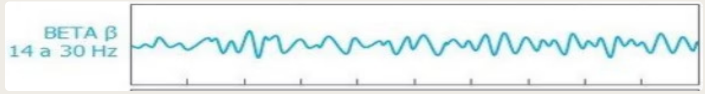
Made with GAMMA

Frequency Bands & Cortical Mapping



Alpha (8-13 Hz)

Relaxation states



Beta (13-30 Hz)

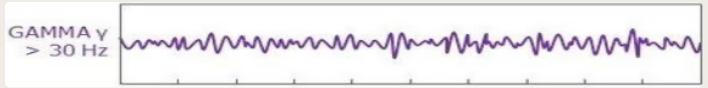
Motor & cognition

1

2

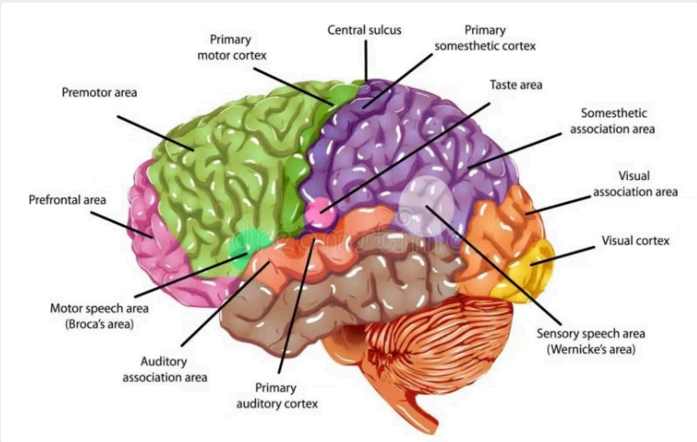
4

3



Gamma (>30 Hz)

Attention & binding



Location

Cortical area mapping

Made with GAMMA

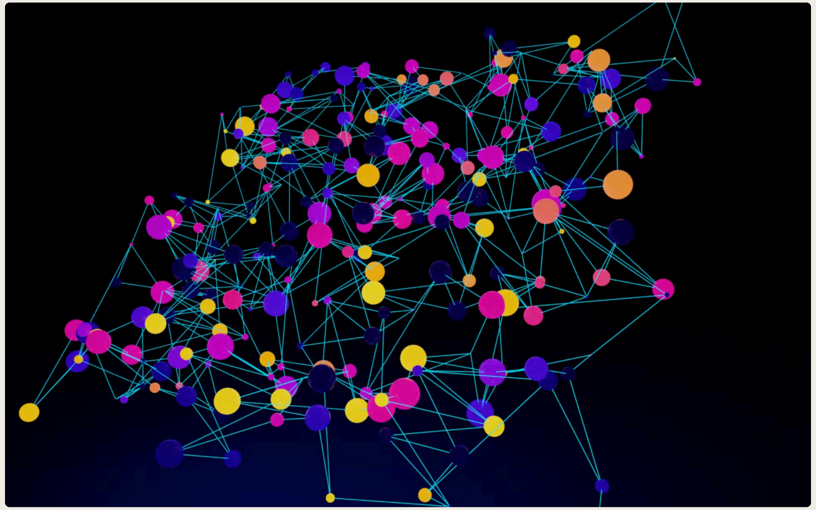
Feature Extraction & Classification

Feature Types

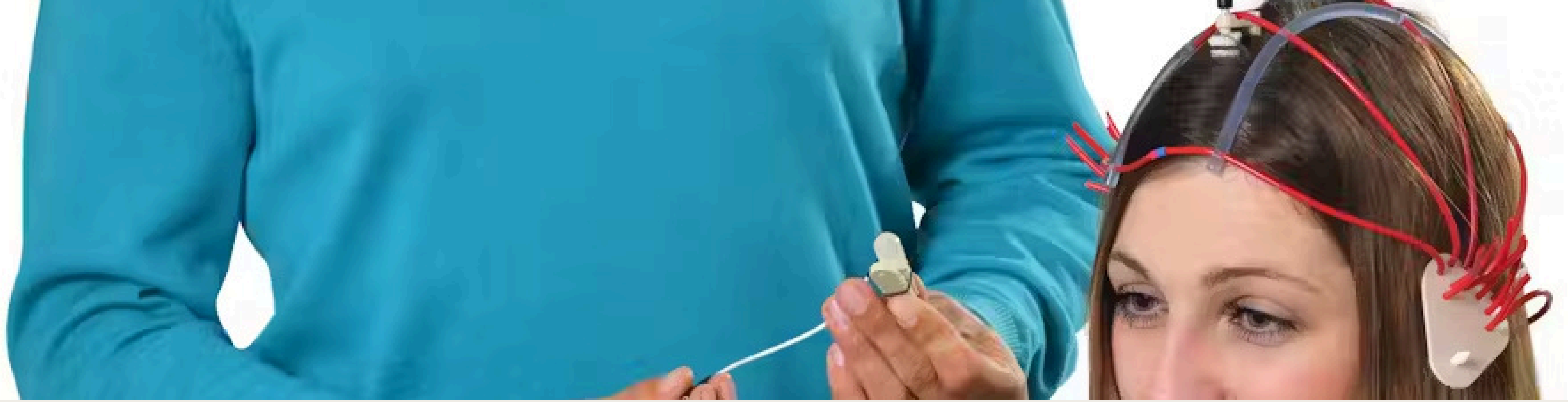
- Frequency power: spectral bands
- P300: event-related potentials
- Time-domain: signal amplitude

ML Algorithms

- Linear Discriminant Analysis (LDA)
- Support Vector Machines (SVM)
- Convolutional Neural Networks (CNN)



Made with GAMMA



BCI Paradigms & Feedback Systems

Motor Imagery

Spontaneous brain rhythm modulation

User voluntarily imagines movement

P300 / SSVEP

Evoked responses to stimuli

External triggers generate signals

Closed-Loop Feedback

Real-time performance improvement

Visual, auditory, tactile responses

Made with GAMMA

Assistive Robotics Applications

Smart Wheelchairs

Thought-controlled navigation with shared control for safety

Assistive Arms

Neural control of robotic limbs for grasping tasks

Made with GAMMA

Neuroprosthetics: Restoring Function

1. **Early Trials**
   Basic grasping and feeding tasks
2. **2022 Breakthrough**
   Bimanual control: cutting and eating
3. **Future Goal**
   Sensory feedback restoration

Invasive implants provide precise control for complex manipulation tasks

Made with GAMMA

Exoskeletons & Teleoperation

Exoskeletons

Used for gait recovery and rehabilitation. A 2019 trial in France successfully enabled a tetraplegic patient to control an exoskeleton for movement.

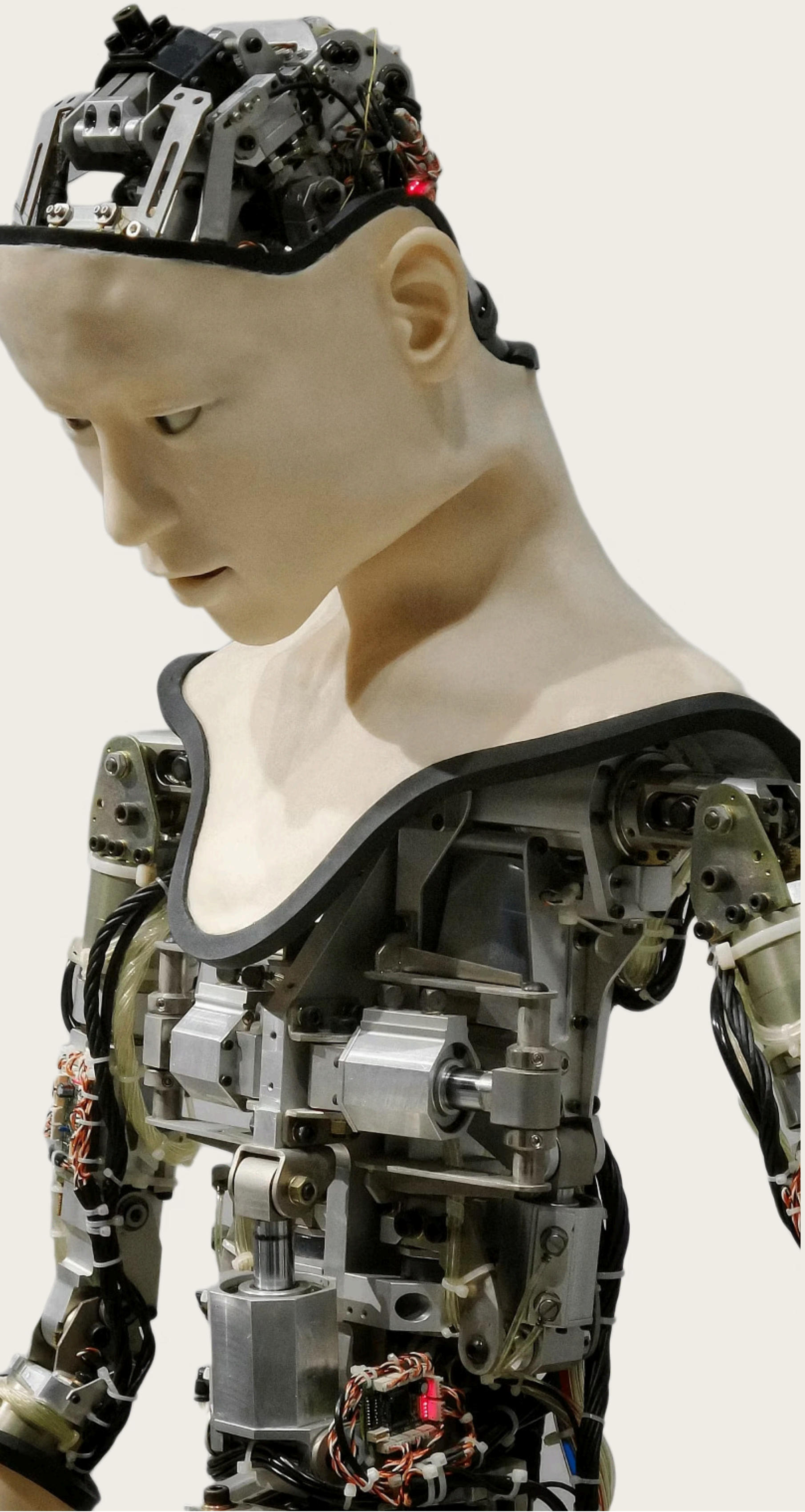
Teleoperation

Control of telepresence robots (like NAO) and drones, allowing users to interact with remote environments.

Beyond the Body

Brain activity extends mobility and presence, enabling individuals to interact with the world and others beyond physical limitations.

Made with GAMMA



Conclusion & Future Directions

Today

Assistive robotics applications are reality

Challenges

Speed, noise, ethics

Future

Hybrid BCIs, AI, feedback systems

Ultimate Goal

Natural and accessible robotic control

Transformation

Of assistive robotics and human-machine interaction

Made with GAMMA