Pipeline

Pre-processing – filtering - Input signal might be very noisy, have outliers, etc.

Low, high, band pass filter, median filter, moving average filter

"window size" - number of data points considered when applying a filter to smooth or transform a signal.

FFT: Transform the signal to the frequency domain using FFT.

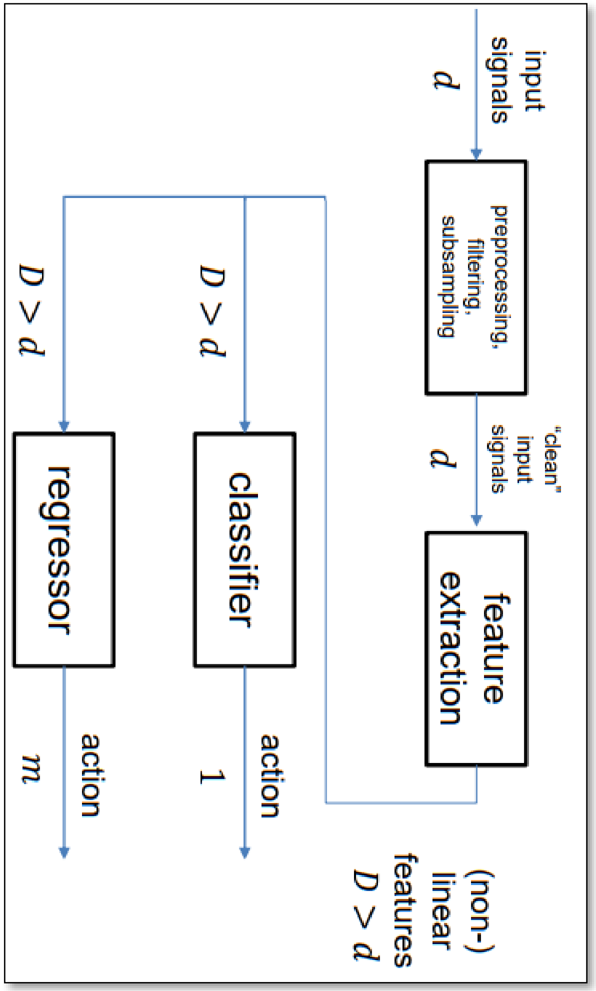
Filtering: Apply the desired filter in the frequency domain.

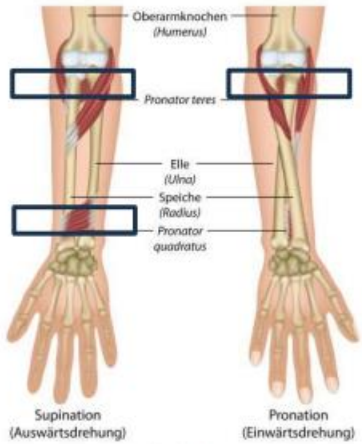
Inverse FFT: Transform the filtered signal back to the time domain.

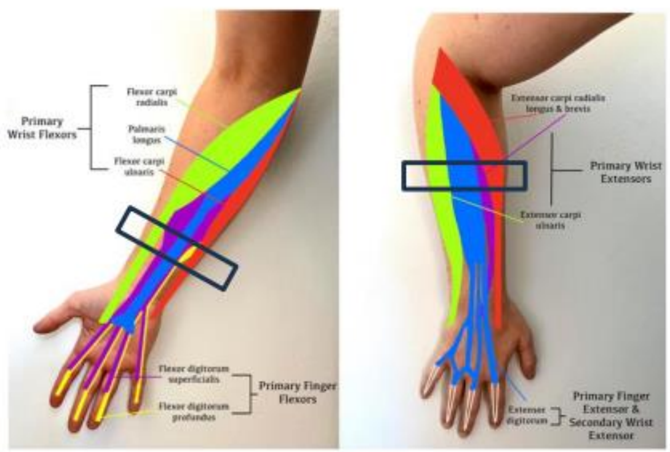
Feature extraction
Eigen values/vectors and co variances
Start with standardization...PCA

Classifier
- Decision Trees
- K-Nearest Neighbours (k-NN)
- Support Vector Machines (SVM)
- Neural Networks

- ***<u>Gather ground truth –</u>*** rather than using sensors to recisely determine it,
- we induce the participant to „try and perform an action"
- we assume „synthetic" ground truth value(s) and artificially associate it to the current signals.







*images not drawn to scale

For input $X = [x_1^T \dots x_n^T]^T \in \mathbb{R}^{n \times d}$ with $x_i = [x_{1,i} \dots x_{m,i}]^T \; i \in [1, \dots, n]$

Standardization $\quad \widetilde{x_{i,j}} = \frac{x_{i,j} - \bar{x}_i}{\sigma}$

Covariance two features/channels $\quad \sigma(x_1, x_2) = \frac{\sum_{k=1}^{m} (x_{k,1} - \overline{x_1})(x_{k,2} - \overline{x_2})}{m}$

Covariance matrix of two features $\quad C_{1,2} = \begin{pmatrix} \sigma(x_1, x_1) & \sigma(x_1, x_2) \\ \sigma(x_2, x_1) & \sigma(x_2, x_2) \end{pmatrix}$

Eigenvalues & -vectors $\quad Ax = \lambda x \Leftrightarrow Ax - \lambda x = 0 \Leftrightarrow (A - \lambda I) \cdot x = 0$

Sensor fusion

EMG and IMU

Sensor fusion involves combining data from multiple sensors to provide a more accurate and comprehensive representation of a system's state

Different Sampling Rates:

Timestamp Misalignment: sensors have different clocks

Noise and Artifacts: Both EMG and IMU data can be noisy. EMG signals can be affected by muscle crosstalk, motion artifacts, and electrical interference. IMUs can be influenced by magnetic interference and sensor drift.

Data Latency: Different sensors may have different latencies, which can cause misalignment in the data streams.

To handle different sampling rates, consider the following methods:

Resampling: Upsample the lower frequency signal (e.g., IMU data) and/or downsample the higher frequency signal (e.g., EMG data) to a common rate. Linear interpolation or more sophisticated methods like spline interpolation can be used for resampling.

Time Alignment: Use the timestamps to align data points. When combining the data, align the higher frequency data (e.g., EMG) to the nearest timestamp of the lower frequency data (e.g., IMU).

To handle timestamp differences, you can:

Synchronization Protocols: Ensure that both sensors are synchronized using a common time source before starting data acquisition. For example, use a shared clock or a synchronization pulse.

Post-Processing Synchronization: Use algorithms to align timestamps after data acquisition. Methods like dynamic time warping (DTW) or correlation-based techniques can help adjust the time series to align data points correctly.

Interpolation: If there are small discrepancies in timestamps, interpolation can be used to estimate the data values at common timestamps.

To handle missing data:

Interpolation: Use interpolation techniques to estimate missing values. Linear interpolation, spline interpolation, or more advanced techniques like Kalman filtering can be used depending on the nature of the missing data and the requirements for accuracy.

Discard Incomplete Data: In some cases, it might be acceptable to discard incomplete data segments if they constitute a small fraction of the dataset and do not significantly impact the overall analysis.

Force Myography (FMG) is a way to detect muscle activity by measuring pressure exerted by the volumetric changes of the muscle contraction. An easy implementation is the usage of pressure sensors in a semi-rigid structure (e.g. socket / housing). Pressure sensors detect the muscle deformation against the structure.

For Tactile Myography (TMG) – also HD-FMG – the same basic principles apply as for FMG. Pressure sensors measure muscle activity exerted by the volumetric changes of muscle contraction. Instead of a single array (e.g. 8) sensors, a much higher number of sensors is used in this case (e.g. 10 modules with 4 x 8 cells = 320 input sensors).

Not influenced by fatigue • Cheaper, simpler electronics • No direct skin contact required - FMG

Placing IMU
Chest (Torso) IMU:

Provides a stable global reference point.
Helps to isolate arm and hand movements from overall body movements.

Upper Arm IMUs:

•Capture shoulder and upper arm movements.

Forearm IMUs:

Capture elbow flexion/extension and forearm rotations.
Example: IMUs mounted on the forearm, near the midpoint between the wrist and elbow.

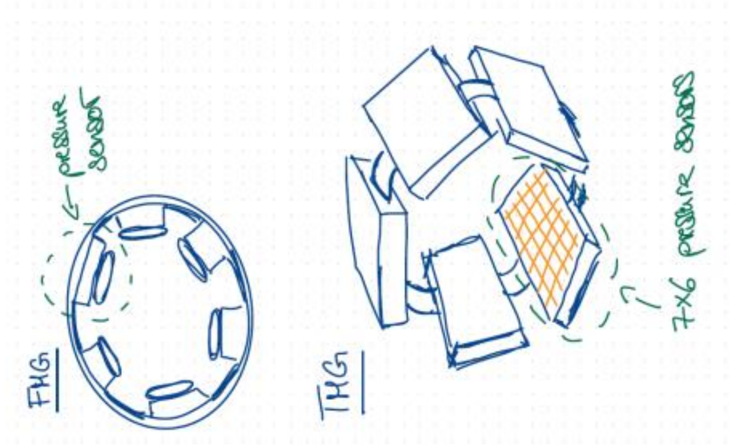
Forearm IMUs:

Capture elbow flexion/extension and forearm rotations.
Example: IMUs mounted on the forearm, near the midpoint between the wrist and elbow.

Hand/Wrist IMUs:
Capture wrist and hand movements.
Inaccurate Positioning:
Loss of Precision:
Unstable Control

By comparing the chest IMU data with the arm/hand IMU data, you can isolate and subtract the body motion, ensuring accurate tracking of the hand's specific pose.

Advantages - FMG



- advantages of FMG over EMG:
  - not influenced by fatigue - EMG signals are affected by muscle fatigue because they measure the electrical activity of muscle fibers, which changes with fatigue. Amplitude Changes: As muscles fatigue, the amplitude of the EMG signal can decrease because the muscle fibers are less able to generate strong contractions.
  - possibly also not by sweat – changes the electrical properties of the skin, conductance increase (saline) – so EMG signal changes. Here the sensors are sealed – sweat wont affect
  - cheaper, simpler electronics
  - Uses force sensing resistors

FMG signals remain consistent and reliable over extended periods, showing less drift or variation compared to sEMG.**Reason**: FMG measures mechanical deformations, which are less susceptible to factors like skin impedance changes, sweat, or electrode displacement that can affect sEMG signals. This stability makes FMG particularly useful for long-term monitoring and applications where consistent signal quality is crucial.

“The frequency of an EMG signal is between 0 to 500 Hz. However, the usable energy of EMG signal is dominant between 50-150 Hz.

Drift in IMUs (Inertial Measurement Units) refers to the gradual deviation of the sensor's reported position, velocity, or orientation over time from its true value. This occurs due to the accumulation of small measurement errors in the accelerometers and gyroscopes, which can be caused by sensor noise, temperature changes, and biases in the sensor. Drift is a common issue with IMUs because these small errors continuously integrate over time, leading to significant inaccuracies in the sensor's output if not corrected.

6. What issues might occur if drift is observed?

- The robots might crash into each other
- There will be an increasing shift in the direction of the drift
- Even if the user does not move, the robots will move

2.2 Solution

1. Changed Parameter: Window size (50ms / 100ms / 150ms / 200ms) => as non-overlapping less points. 5

2. Advantage: Better separability between movements; Disadvantage: Higher Delay due to window size! 2.5 + 2.5

3. Unsupervised, Advantage: No labels needed => no training phase / potential to keep learning all the time. 2.5 + 2.5

How does the pressure change during a walking cycle?
The image depicts the pressure distribution on the feet during different phases of the walking cycle. The walking cycle is divided into two main phases: the stance phase and the swing phase. Each phase consists of several sub-phases. Here's a breakdown of the terms and the overall image:

Stance Phase:

1.HS (Heel Strike):

1. The moment the heel first makes contact with the ground.
2. Pressure is concentrated on the heel.

2.FF (Foot Flat):

1. The entire foot is in contact with the ground.
2. Pressure distribution spreads across the whole foot.

1.MSt (Midstance):

1. The body's weight is directly over the supporting foot.
2. Pressure is more evenly distributed.

2.HO (Heel Off):

1. The heel lifts off the ground, transferring weight to the forefoot and toes.
2. Pressure shifts towards the ball of the foot and toes.

During a walking cycle, the pressure on the feet varies significantly. Initially, when the heel strikes the ground (heel strike), there is a high pressure on the heel. As the body moves forward, the pressure shifts to the midfoot (midstance) and then to the ball of the foot and toes (toe-off) as the foot pushes off the ground. This dynamic shift in pressure helps in propelling the body forward and maintaining balance during walking

1. **Swing Phase:**

1.TO (Toe Off):

1. The toes push off the ground to propel the body forward.
2. Pressure is concentrated on the toes.

2.IS (Initial Swing):

1. The foot lifts off the ground and moves forward.
2. Minimal to no ground contact, so no pressure distribution shown.

3.MSw (Mid Swing):

1. The leg swings through under the body.
2. The foot is in the air, so no pressure distribution shown.

4.HS (Heel Strike):

1. The heel strikes the ground again, beginning a new cycle.
2. Pressure is concentrated on the heel.

What else can you detect using pressure insoles or pressure plates?

1. Walking cycle - Pressure Distribution Across Sensors
2. Analysis of different regions of the foot: outside, medial, and inside.

3. Temporal data can detect how pressure shifts dynamically during different activities, providing insights into gait cycles and specific movements.

4. How pressure distribution changes during different activities

Posture Assessment: Understanding weight distribution to identify and correct postural imbalances.

Athletic Performance Monitoring: Evaluating foot pressure during different sports activities to optimize performance and reduce injury risk.

Rehabilitation Monitoring: Tracking pressure changes to assess the progress and effectiveness of rehabilitation exercises for lower limb injuries.

Check if the patient wants to stop or continue

What are the benefits of Ultrasound with respect to EMG and FMG?

Benefits of Ultrasound in Prosthetics Compared to EMG

1.**Detailed Visualization**: Ultrasound provides real-time images of muscles and tendons, offering more precise information about muscle movements and conditions.
2.**Depth Information**: Captures data from deeper muscles that EMG surface electrodes cannot access.
3.**Non-Invasive**: Avoids the discomfort and potential risk of infection associated with needle electrodes used in some EMG applications.
4.**Functional Analysis**: Allows for the observation of muscle structure and function during movement, aiding in more accurate prosthetic control.

Benefits of Ultrasound in Prosthetics Compared to FMG

1.**Structural Insight**: Ultrasound gives clear images of muscle shape, size, and condition, which FMG cannot provide.
2.**Dynamic Assessment**: Can observe and assess muscle function in real-time, enhancing the accuracy of prosthetic control during different activities.
3.**Tissue Differentiation**: Effectively differentiates between various tissue types (muscle, tendon, fat), providing more comprehensive data than FMG, which only measures surface pressure changes.
4.**Precise Localization**: Ultrasound can precisely localize the source of muscle movements, improving the targeting and effectiveness of prosthetic control mechanisms.

Imagine you combine a pressure sensor for the hand with an exoskeleton. Which user groups could benefit from that?

1.During training if no senses in hand then they could Measure how much pressure is applied and give feedback
2. Harvesting robot

3.Rehabilitation Patients: Those undergoing physical therapy for hand injuries could use the exoskeleton to aid in their recovery and improve strength and coordination.

4.Industrial Workers: Workers performing repetitive or strenuous tasks could use the exoskeleton to reduce fatigue and prevent injuries

How could you use flex sensors to overcome back pain?

to monitor and correct posture

These sensors can detect the bending or flexing of the back and provide real-time feedback to the user
if the user slouches or adopts a poor posture, the device can alert them to correct their posture, thereby reducing the strain on the back muscles and spine over time

Upper back - Thoracic Spine
Lower back - Lumbar Spine
Shoulders
Neck,hips

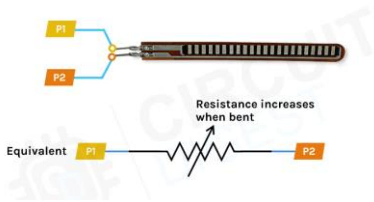
To what kind of wearables could you easily add them?

Straps around the chest

Smart clothing

Fitness trackers

Rehabilitation Devices:
Wearables used in physical therapy to monitor and guide movements during exercises.



Benefits and Drawbacks of External Sensors

Benefits:

Accuracy: External sensors can provide highly accurate and reliable data.

Specialization: They can be specifically designed to measure particular metrics such as pressure, movement, or posture.

Non-Invasive: They do not require any surgical procedures, making them safer and more user-friendly.

Drawbacks:

Bulkiness: External sensors can be cumbersome and uncomfortable to wear.

Cost: High-quality external sensors can be expensive.

Data Management: They often require additional devices or software to collect and interpret the data.

Take time to set up

What sensors might be preferred during rehabilitation? Why?

External – if we are in a clinic, then no human errors
Else use wearable – if we can walk

What kind of sensors does (nearly) every participant already have with him/her?

•Smartphone
Sensors:Accelerometer and Gyroscope**:** Track movement and orientation.
Camera**:** Visual analysis and feedback
Microphone: Voice commands and audio feedback
Proximity and light sensors,IMU

Watches – track sleep,exercise

What is the difference between the sensors used during a session at the physio therapist and at home?

Physiotherapist Sessions:

Sensors: High precision, specialized sensors (e.g., high-resolution pressure plates, professional-grade EMG).

Monitoring: Detailed and comprehensive, under professional supervision.

At Home:

Sensors: Consumer-grade sensors (e.g., smartphone sensors, simple wearables).

Monitoring: Basic monitoring and feedback, focusing on adherence to exercise routines.

Feedback exercise

Visual Feedback

• Important for telemanipulation • Helps if system is precise but not accurate • Very intuitive • (Most of the time) easy to understand • Humans are pretty used to it from daily life

Haptic Feedback:

Technology Used: Uses devices like vibration motors.

Purpose: Creates physical sensations to mimic touch experiences.

Tactile Feedback:

Technology Used: Uses physical buttons, textures, and other tangible elements.

Purpose: Enhances the sense of touch through real physical elements.

Tactile feedback -
Sensing different materials
Sensing different textures
Haptic feedback - Sensory Feedback: Incorporating tactile sensors in prosthetic limbs to provide feedback about pressure, texture, and temperature. This can help amputees better control and feel their prosthetics, making them more functional and intuitive to use.

Vibration Motors: Embedding small vibration motors to simulate different tactile sensations, enabling amputees to distinguish between different types of surfaces or detect when they are holding an object.

Sensory substitution is a change of the characteristics of one sensory modality into stimuli of another sensory modality.

3 parts: a sensor, a coupling system, and a stimulator. The sensor records stimuli and gives them to a coupling system which interprets these signals and transmits them to a stimulator

This involves providing feedback to the user through changes in temperature (heat or cold).

Examples:

•**Haptic Devices:** Devices that simulate touch-related experiences by altering temperature, such as feeling warmth when touching a virtual object.

•**Wearables:** Smart clothing or accessories that change temperature to signal alerts or provide comfort adjustments.

•**Virtual Reality:** VR systems that create immersive environments by varying temperature to match the virtual scene.

IMU and prosthetic hand - The IMU could be used to determine the orientation of the prosthesis holding the coffee and this could be used to adapt the orientation of the prosthetic hand if it is moved to overcome spilling.

Filter - **EMG** – frequency for ID - 50-150Hz

A band-pass filter for the range of [50Hz, 150Hz]

A common choice for EMG signal processing is the Butterworth filter due to its flat frequency response in the passband.

FE – Amplitude high -> more force

- Amplitude of the EMG
- Continuous EMG signal over a specific threshold - Ensures that the muscle activity stays above a certain level for a sustained period, which is crucial for stable and controlled actions, such as holding a paper cup without deforming it.
- Frequency Content of the EMG Signal

- Determine the intent from the features in EMG-If the amplitude of the EMG if over an specific threshold a
- If the amplitude of the EMG is below a specific threshold b (in case someone wants
- Continuous EMG signal (95% of the values) in the threshold range [a,b] over more than 2s
- 0-1 second: Sharp rise in the EMG signal.
- 1-2 seconds: Amplitude fluctuates as the grip is adjusted.
- 2-10 seconds: Steady amplitude, maintaining a consistent level of muscle contraction.

How could you use shared autonomy to grasp the paper cup using the IMU as input?

The human moves the hand to the paper cup and the hand. Once it is grasped, the prosthesis autonomously tries to keep it at a reasonable orientation to overcome spilling.

- Euler angles: might lead to singularities
- Rotation matrix: higher computation effort

Damage check
Temp and force sensors help

Feedback on temp– through LED and auditory alerts

- Stimuli generated - Pressure on the prosthetic hand, with a pressure sensor at the fingers
- Deformation of the paper cup, with a camera

How could you preprocess the data from the temperature sensor?

You could use subsampling and define the threshold if you e. g. measure more than 75°C it belongs to bin 4. It is a 3 in the interval]75°C, 50°C]. And so on…

classify temperature readings into predefined bins or categories based on thresholds

preprocessing involves transforming and categorizing continuous temperature readings into discrete categories

DIY:

Prosthetic Limb Control:
Functionality Indication: Audio cues can signal the status of different functions (e.g., gripping strength, mode switching).
Error Notification: Alerts when something goes wrong or if adjustments are needed.
Sensory Substitution:
Tactile Information: Audio feedback can represent tactile sensations such as texture, temperature, and pressure by mapping these sensations to specific sounds or tones.
Environmental Awareness: Sounds can provide information about surroundings, helping amputees navigate safely.

In what situations is audio feedback helpful?

Accessibility: For individuals with visual impairments, audio feedback provides essential information that they cannot obtain visually.

Environmental Constraints: In dark or low-visibility environments, audio feedback ensures that users can still receive necessary information.

When is audio feedback superior to visual feedback?

Attention Management: Audio feedback can capture attention more effectively in scenarios where visual attention is divided, such as driving or multitasking.
Mobility and Portability: Audio feedback is more practical when users are on the move and cannot constantly look at a screen.
Alerting and Alarming: For critical alerts, such as emergency alarms or timer notifications, audio feedback is more effective in grabbing immediate attention.
Situational Awareness: In environments where maintaining situational awareness is crucial, like during sports or while operating machinery, audio feedback provides essential information without the need to divert visual focus.

Where is audio feedback used in our daily life?

Smartphones: Ringtones, message alerts, and voice assistants (e.g., Siri, Google Assistant).
Home Appliances: Beeps from microwaves, washing machines, and dishwashers indicating the end of a cycle.
Vehicles: Audible signals for seatbelt reminders, turn signals, and parking sensors.
Computers and Gadgets: Error beeps, notification sounds, and startup chimes.
Public transport: Announcements

How could you use audio feedback for assistive devices?

Screen Readers: For individuals with visual impairments, screen readers convert text on a screen into speech, allowing them to navigate and interact with digital content.
Auditory Alerts: Devices can use sounds to alert users to changes or important events, such as medication reminders or changes in health metrics.
Voice Commands: Assistive devices can be controlled using voice commands, providing an interactive and accessible way for users to manage technology.
Environmental Sensors: Devices that detect obstacles or changes in the environment (e.g., for the visually impaired) can provide audio cues to navigate safely.
Feedback for Wearables: Wearable devices, such as fitness trackers, can use audio feedback to inform users about their progress or health status without requiring visual confirmation.

What happens to magnetometer, if you are at the north pole?

At the magnetic North Pole, the magnetic field lines are vertical, pointing directly downwards into the Earth. The horizontal component of the magnetic field (parallel to the Earth's surface) is essentially zero. The magnetometer might produce unstable or rapidly fluctuating directional readings because it cannot reliably detect a stable horizontal field.

What could disturb a magnetometer?

Electromagnetic Interference

Magnetic materials

Metal Objects - Distorted Readings: - ferromagnetic materials magnetized

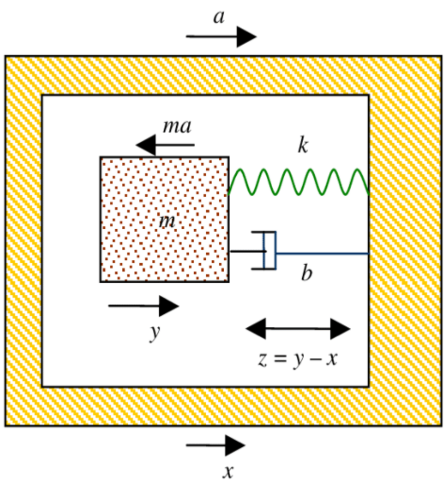
IMU and stiffness
spring stiffness – k - **Sensitivity**: The stiffness of the spring affects the sensitivity of the IMU. A stiffer spring (k is large) will result in less displacement for a given acceleration, which can reduce the sensitivity of the accelerometer. Conversely, a less stiff spring (k is small) will allow more displacement, increasing sensitivity.

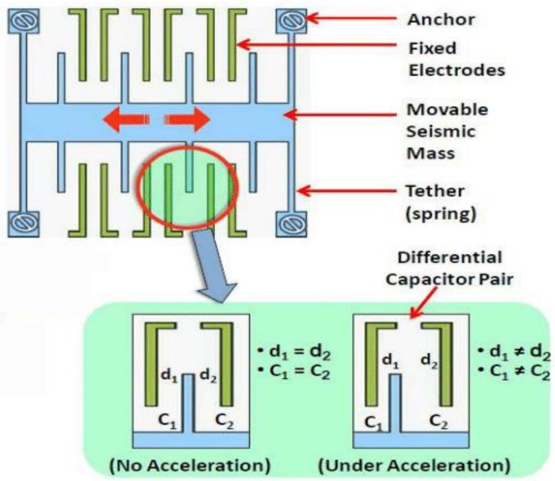
Dynamic Range: Stiffer springs can handle higher accelerations without significant displacement, thus increasing the dynamic range. However, if the spring is too stiff, the IMU may not be sensitive enough to detect small accelerations.

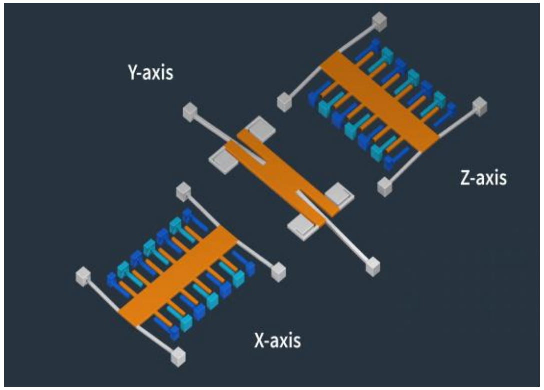
Natural Frequency: The natural frequency of the system is given by $\omega n=\sqrt{k}/m$, where m is the mass. Higher spring stiffness increases the natural frequency. This affects how the system responds to dynamic inputs and its ability to filter out high-frequency noise

Hooke's law states that F = kx, x -the amount by which the free end of the spring was displaced from its "relaxed" position

Damping - Appropriate damping can improve the accuracy of the IMU by minimizing oscillations and noise. Under-damped systems can oscillate and produce inaccurate readings, while over-damped systems may respond too slowly to changes in acceleration.- good for fast motions







FMG and op amp
An operational amplifier (OpAmp) is a semiconductor-based circuit element which, in its ideal form, adjusts its output voltage so that the currents flowing in its input terminals is equal to zero, as is the diffrence in voltage between the terminals themselves.

The sensors in FMG systems generate small electrical signals corresponding to the muscle force or pressure applied. These signals are often too weak to be directly analyzed or used.

OpAmps - amplifiers to amplify the small differential signals from the sensors. This amplification makes the signals strong enough for further processing and analysis.

High Gain: The high gain provided by OpAmps ensures that even minute changes in muscle force are captured accurately.

Also to reduce noise

Imagine a set of FSR sensors in a bracelet. What would you imagine could be problematic when measuring a muscle bulging?

Because the overall pressure, sumed over all area units, has to be zero in static conditions, one muscle bulging up on one side of the segment will cause pressure on the opposite side as well, leading to cross talk.

Independent Component Analysis could solve this problem. By applying ICA, the mixed signals from the sensors can be decomposed into independent components. This helps in isolating the true muscle bulging signals from the interfering signals.

Somatosensory feedback is biological feedback provided to the somatosensory system – in practice, touch and force feedback. In other words, feedback proximal to the body, or feedback which is neither auditory nor visual. Concrete scenario: the end-effector of an assistive device touches an object, and corresponding somatosensory feedback is given to the user in real time.

Body-powered upper-limb prostheses naturally provide force feedback due to their actuation via cables. User has prosthesis grab a glass, and the reaction forces perceived by the user help him determine the weight of the glass (empty / half full / full).

Exoskeleton for upper-arm rehabilitation - All exoskeletons inherently provide somatosensory feedback due to their nature. Here’s how:

•**Physical Interaction**: The user directly interacts with the exoskeleton, feeling the resistance and support it provides. This resistance helps you understand how much effort you need to move .

•Force and torque sensors can be embedded in the joints of the exoskeleton in order to modulate the “resistance” and provide, e.g., friction compensation, gravity compensation, active resistance, virtual obstacles, trajectories to be followed, etc.

Somatosensory feedback is the sensation you feel from your muscles, joints, and skin that helps you understand how your body is moving and how much force you are using.

what is it?

Tomography ("writing with slices") is about reconstructing an image by sending multiple waves into a sample and recording, for each wave, either the echoes of the wave where it was sent off, or the attenuation profile at the other end of the sample. Each wave is sent from a different angle with respect to the sample, so that in the end multiple "points of view" are gathered together.

what kind of information does it yield?

When correctly focussed, it is able to yield a complete view of a "slice" of the sample (cross-section) without the need to cut into it, but just to send energy into it.

why would such techniques be useful at all for intent detection?

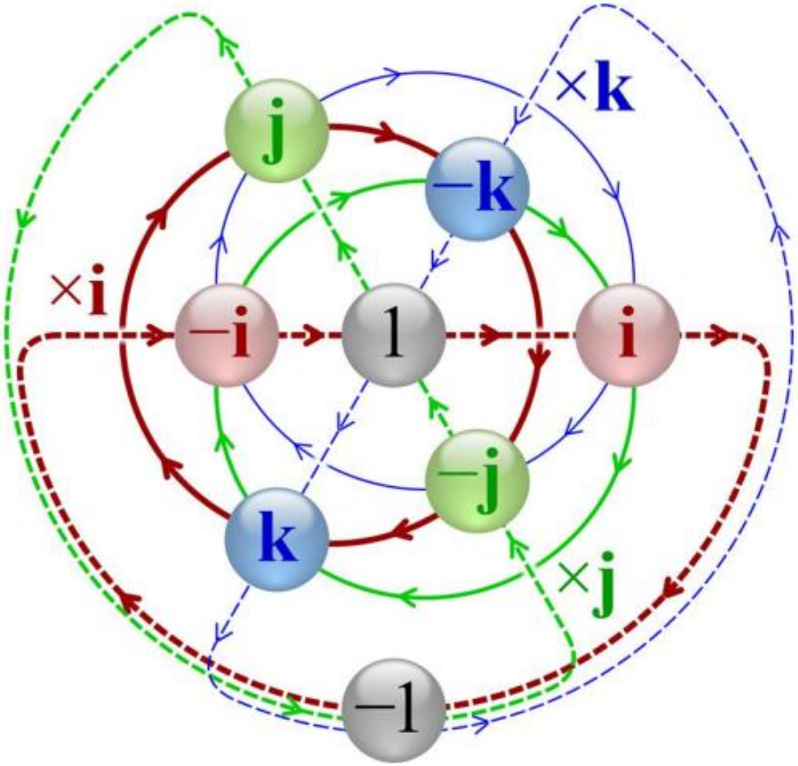
The intent to move produces motion of all internal structures of a body part involved with such a motion. Such information, gathered by tomography, can be used to estimate what the (intended) motion is, for example by targeting muscle belly deformation.

what makes them different from, e.g., EMG?

Tomography can yield useful information about the activity going on in the depth of the body, which surface techniques such as EMG are typically at odds with. For instance, wrist rotation is actuated by deep muscles, making it hard for surface techniques to correctly gather it. Tomography can help by directly visualising the motion and deformation of such deep muscles.

In general, a device designed for intent detection should have high sampling rate, high resolution, low power consumption, low heat production, and lowest possible injection of energy into the tissues. List and discuss what factor(s) need be taken into account when designing an EIT device, in order to find the right balance among the above-specified requirements. (Write no more than two paragraphs.) **(20%)**

In the case of EIT, all these requirements critically depend on the number of electrodes used. An EIT device with many electrodes has a high resolution, but requires more power, produces more heat, injects more energy into the user and implies a lower sampling rate.



$$\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = \mathbf{ijk} = -1$$

$$\mathbf{ij} = -\mathbf{ji} = \mathbf{k}, \quad \mathbf{jk} = -\mathbf{kj} = \mathbf{i}, \quad \mathbf{ki} = -\mathbf{ik} = \mathbf{j}$$

$$\mathbf{q} = (a, b, c, d) \coloneqq a + b\,\mathbf{i} + c\,\mathbf{j} + d\,\mathbf{k}$$

$$\mathbf{q} = s + v_x\,\mathbf{i} + v_y\,\mathbf{j} + v_z\,\mathbf{k} =: s + \vec{v} =: (\underbrace{s}_{\text{Scalar part}}, \underbrace{\vec{v}}_{\text{Vector part}}) \quad \in \mathbb{H}$$

$$\bar{\mathbf{q}} \coloneqq (s, -\vec{v})$$

$$\mathbf{q}\bar{\mathbf{q}} = (s, \vec{v})(s, -\vec{v}) = (s^2 + |\vec{v}|^2, 0) =: |\mathbf{q}|^2$$

$$\mathbf{q}\underbrace{(\bar{\mathbf{q}}/|\mathbf{q}|^2)}_{\overset{!!}{\mathbf{q}^{-1}}} = 1$$

$$\mathbf{q}_1\mathbf{q}_2 = (s_1,\ \vec{v_1})(s_2,\ \vec{v_2})$$
$$= (s_1 s_2 - \vec{v_1}\cdot\vec{v_2},\ s_1\vec{v_2} + s_2\vec{v_1} + \underbrace{\vec{v_1}\times\vec{v_2}}_{\text{Cross-product makes it non-commutative}})$$

$$\mathbf{q} = (a, b, c, d) \coloneqq a + b\,\mathbf{i} + c\,\mathbf{j} + d\,\mathbf{k}$$

$$\mathbf{q} \coloneqq (\cos\theta\,,\ \vec{u}\sin\theta)$$ where $|\vec{u}| = 1$, i.e. $|\mathbf{q}| = 1$

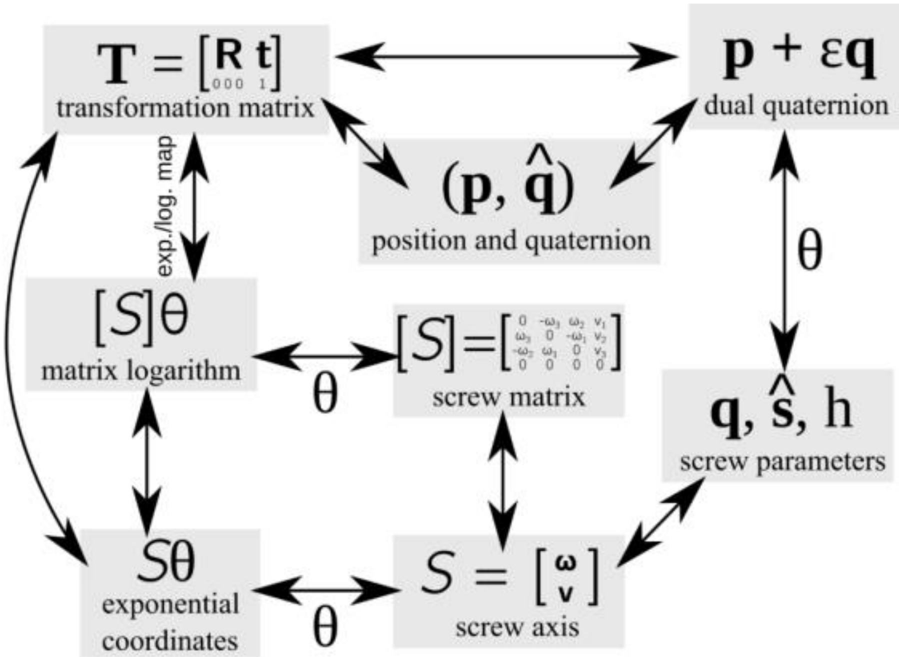
- Singularity-free
- Un-ambiguous
- Shortest path interpolation
- Most efficient and compact form for representing rigid transforms [SCHI11] - (3x4 matrix 12 floats compared to a dual-quaternion 8 floats)
- Unified representation of translation and rotation
- Can be integrated into a current system with little coding effort
- The individual translation and rotational information is combined to produce a single invariant coordinate frame [GVMC98]

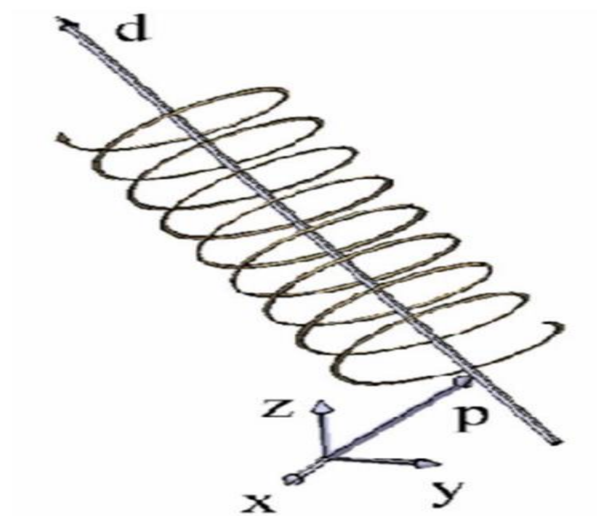
$$\mathbf{q}_r = [\cos(\frac{\theta}{2}), \mathbf{n}_x \sin(\frac{\theta}{2}), \mathbf{n}_y \sin(\frac{\theta}{2}), \mathbf{n}_z \sin(\frac{\theta}{2})][0,0,0,0]$$

$$\mathbf{q}_t = [1,0,0,0][0, \frac{\mathbf{t}_x}{2}, \frac{\mathbf{t}_y}{2}, \frac{\mathbf{t}_z}{2}]$$

$$\mathbf{q} = \mathbf{q}_t \times \mathbf{q}_r$$

$$\mathbf{p}' = \mathbf{q}\mathbf{p}\mathbf{q}^*$$






```
// Initialise mav_S => 2 %
zc_S <- ∅
// get number of windows => rounded! => 3 (was 4) %
num_wins <- (int)(|raw_S| / n) // or anything else to round to int
// loop over num wins  => 3 (was 5) %
for i <- 0 to num_wins do
  // get corresponding window => 2 (was 4) %
  w <- raw_S[i*n:(i+1)*n]
  // calculate the zc and write => 10 (was 5)%
  zc <- 0
  for j <- 0 to |window|-1 do
    if((w[j] < 0 && w[j+1] > 0) || (w[j] > 0 && w[j+1] < 0)) then
      zc <- zc + 1
  zc_S[i] <- zc
end for
```

Pros & cons

- IMUs
  - **accurate, cheap, easy to condition**
  - **need to wear (many of) them, drift**
  - **seemingly more useful in lower-limb prosthetics**
- FMG
  - **cheap, high-density, stable**
  - **prone to movement artefacts, limb position effect**
  - **features and processing unclear**
- EIT
  - **yields info about deep structures**
  - **cheap, wearable**
  - **processing unclear**
  - **minimally invasive (injection of current)**
- US
  - **extremely rich in infomation**
  - **surprisingly easy *digital* processing**
  - **not (yet) cheap at all**
  - **miniaturisation is a problem**
- sEMG
  - **cheap, high-density, stable**
  - **prone to movement artefacts, fatigue, crosstalk**
  - **features and processing defined**

Solution ideas:

1) "Think about performing the correct movement"
   - In case of congenitial amputation X
2) "Do the same movement with both sides"
   - Does not work for bilateral (both sides) amputation X
3) "Just produce signals patterns, which you can distinctly repeat"
4) Start with some signals and update model incrementally

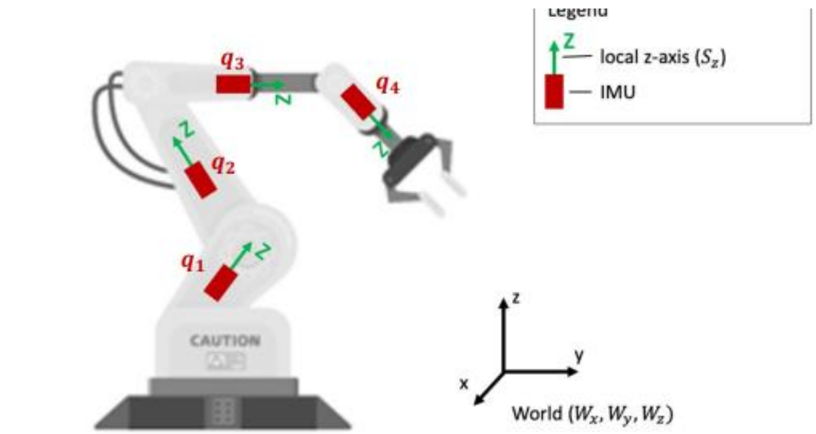


Figure 2 - IMU placement