IDF Winter semester 2022 – Exam

Matr. Nr. **Your name:** **Your surname:**

Question #1: (30%)

Tomography: **(10%)**

- 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.

During the course we explored ultrasound scanning and EIT.

- 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.

Question #2: (35%)

2.1 (20%) Pseudo Code

Implement a Pseudo Code which iterates over a Set **`raw_S`** of a single channel sEMG observations (=> **`raw_S[i]`** is a single sEMG value). Calculate the feature "Zero Crossings (ZC)" of non-overlapping windows of length **`n`** and write it to a new Set **`zc_S`** (=> each window is one value in **`zc_S`**). *(Orientation: ca. 9 lines)*. Assume that your signal is noise-free and all zero-crossings count (so you <u>don't need to check</u> against the noise threshold).

If the last window has fewer samples than the window size, it can be discarded. Assume that indexing starts at **`0`**. If S is a set, then **`S[start_included:end_excluded]`** defines a slice of this Set. Furthermore, for logical **and** / **or** statements symbols **&&** / **||** can be used. Same as in the exercises, the length (number of entries) of a Set **`S`** can be stated as **`|S|`**.

Recommendation: Use comments to make sure your code is understandable (especially if you deviate from the code convention introduced in the exercise)

2.1 Solution

```
// Initialise mav_S => 2 %
zc_S <- Ø

// get number of windows => rounded! => 4 %
num_wins <- (int)(|raw_S| / n) // or anything else to round to int

// loop over num wins  => 5 %
for i <- 0 to num_wins do
    // get corresponding window => 4 %
    w <- raw_S[i*n:(i+1)*n]
    // calculate the zc and write => 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
```

2.2 (15%) PCA Analysis

The following four scatter plots based on labeled sEMG data consist of the hand's rest, flexion, and extension movements. First, all Hudgins Features were calculated with non-overlapping windows, then a dimensionality reduction to 2 dimensions was conducted through a PCA.

The four outcomes (four scatter plots) only differ in one changed parameter during the calculation of the Hudgins features.

1. State which changed parameter could be responsible for the depicted change. *(1 sentence)*
2. State an advantage and a disadvantage that are inflicted by the increase of this parameter in the context of machine learning for prosthesis control. *(2 bullet points)*
3. State if a PCA is a Supervised or Unsupervised Machine Learning method and think of an advantage this method could have in prosthesis control (1-2 sentences)

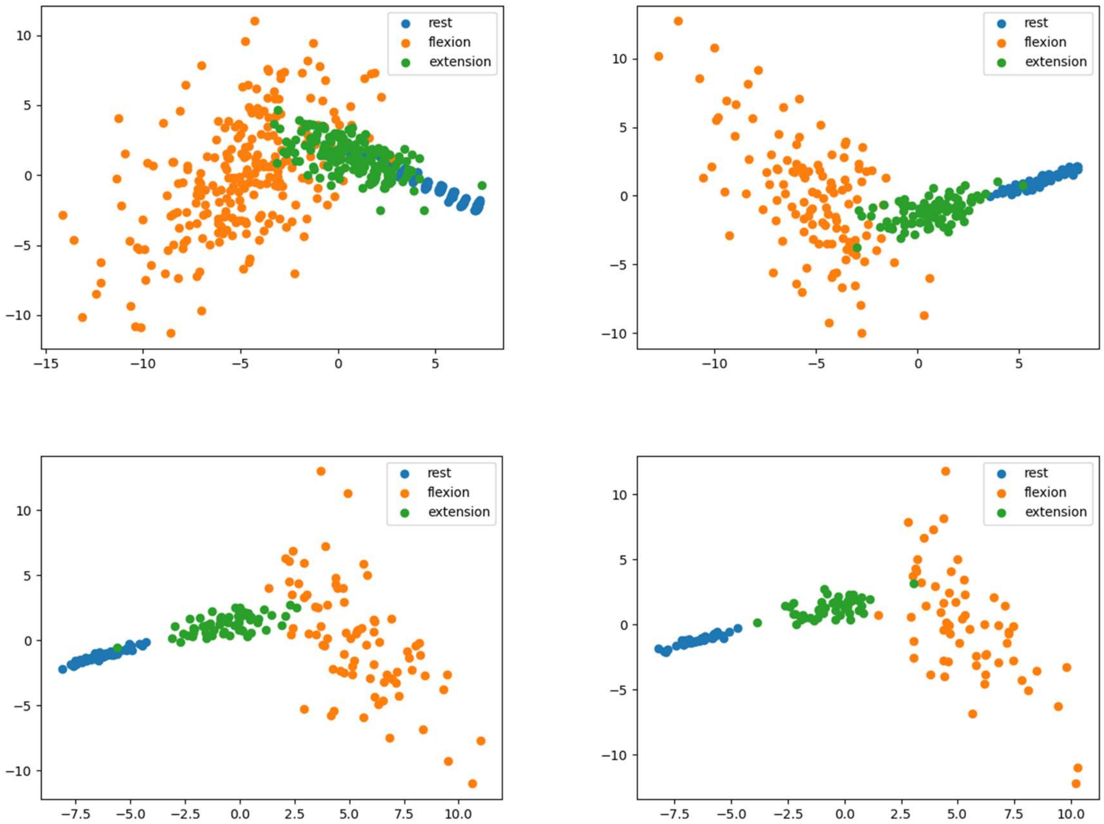


Figure 1 - PCAs

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

Question #3: (40%)

3.1 (20%) Kinematic Chain / Quaternions - The Bosch IMU BNO055 includes a sensor fusion that can provide an absolute orientation in the form of a unit quaternion in the world frame W. The sensors are aligned in a way that the x-axis S_x of the local sensor frame S points in the direction depicted below (Figure 1). Furthermore, assume that the kinematic chain (Figure 2) depicted below is valid. Calculate the position of p_4 and the Euclidean distance between p_0 and p_4 in the world frame W under the assumption that p_0 lies in the origin of the coordinate frame. Conversion from pure quaternion to vector can be notated in the following way:

$$pure\ quaternion \rightarrow vector\colon\ \boldsymbol{p_i} = vec(q_{p_i})$$

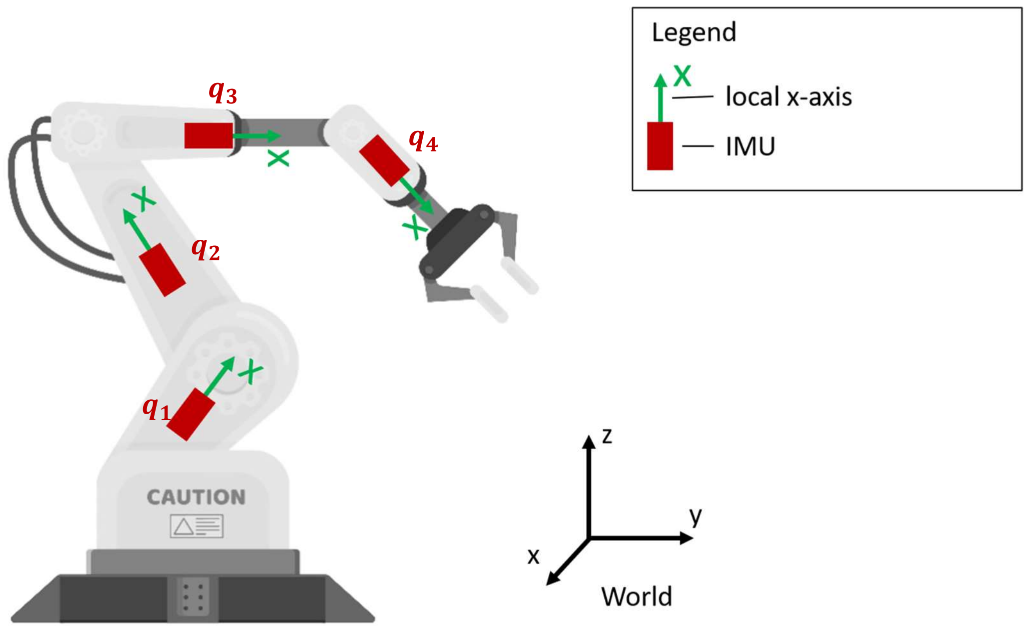


Figure 2 - IMU placement

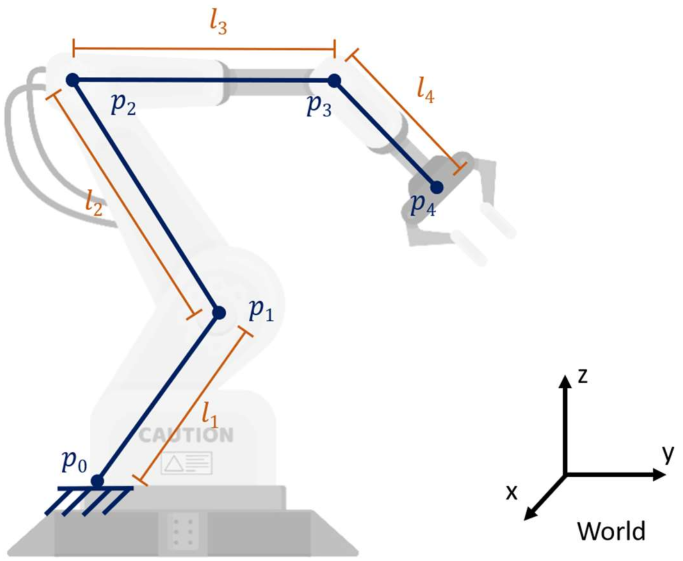


Figure 3 - Kinematic Chain

3.1 Solution

Solution 3.1

1. Define pure quaternions from l_s:

$q_{l_1} = [0 \; l_1 \; 0 \; 0]$ $\quad q_{l_3} = [0 \; l_3 \; 0 \; 0]$

$q_{l_2} = [0 \; l_2 \; 0 \; 0]$ $\quad q_{l_4} = [0 \; l_4 \; 0 \; 0]$

2. Calculate p_4 in the world frame

$\left[q_{p_1} = q_1 \, q_{l_1} \, q_1^* \right]$ not necessary

$$q_{p_4} = q_1 \, q_{l_1} \, q_1^* + q_2 \, q_{l_2} \, q_2^*$$
$$+ q_3 \, q_{l_3} \, q_3^* + q_4 \, q_{l_4} \, q_4^*$$

$$\vec{p}_4 = \text{vec}(q_{p_4})$$

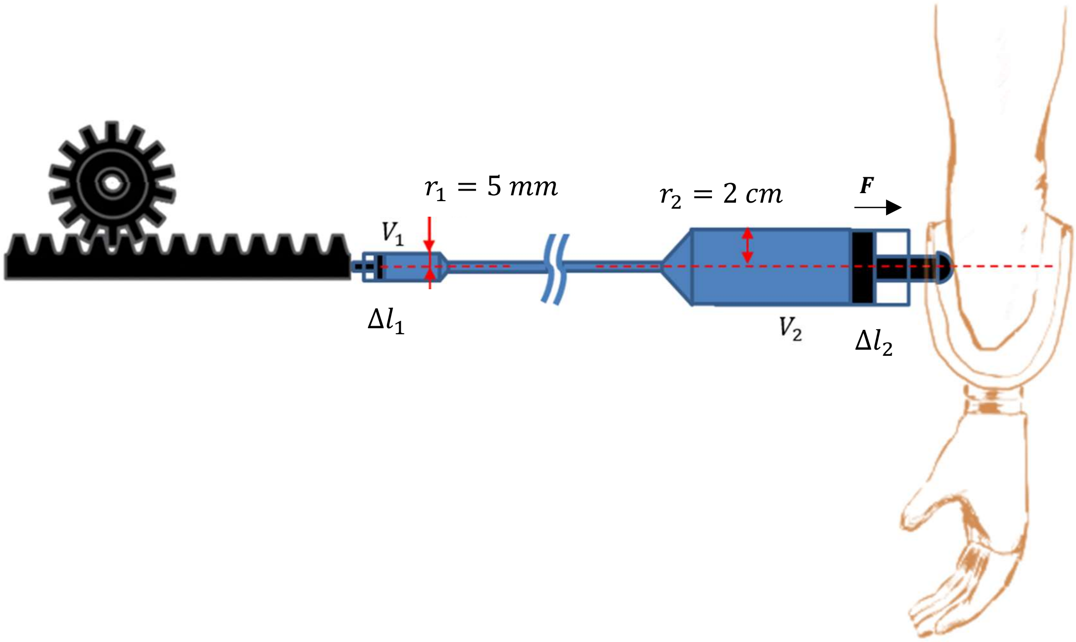
3. Distance

$$\vec{d} = \vec{p}_4 - \underbrace{\vec{p}_0}_{(0\,0\,0)}$$

$$|\vec{d}| = \sqrt{d_x^2 + d_y^2 + d_z^2}$$

3.2 (15%) Somatosensory Feedback - Consider this electromechanical tactile feedback actuator. The linear actuator on the left-hand side shifts the piston of a cylindrical syringe connected through a tube with a different cylindrical syringe on the right-hand side, whose piston pushes against the user's stump. The system is filled with uncompressible fluid, meaning that both the total volume of the fluid and the pressure on the walls of the vessel are constant.

Consider that the stump has an average compliance of $0.1\ cm/N$ and that we want to exert a force F on the stump of up to $1\ N$. What displacement Δl_1 would we need to exert that force on the stump (= the minimal length of the linear gear)? Remember that the change in volume in the first syringe corresponds to the same change in volume in the second syringe $\Delta V_1 = \Delta V_2$.



3.2 Solution

Calculate Δl_2: 5

$$\Delta l_2 = 1\ \mathrm{N} \cdot 0.1\ \mathrm{cm/N} = 0.1\ \mathrm{cm}$$

Calculate $\Delta \mathrm{l}_1$: 10

$$\Delta V_1 = \Delta V_2$$

$$\Delta l_1 \pi r_1^2 = \Delta l_2 \pi r_2^2$$

$$\Delta l_1 = \Delta l_2 \frac{r_2^2}{r_1^2}$$

$$\Delta l_1 = 0.016\ \mathrm{m} = 16\ \mathrm{mm}$$