23SS_IDF – Exam

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

Question #1: (30%)

Somatosensory feedback:

1. Describe somatosensory feedback, as seen in our course, in a paragraph. Describe a concrete scenario in which somatosensory feedback could be very useful.
   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.

2. Is there some kind of prosthetic device which provides somatosensory feedback "by its own nature"? if so, which one, and how? Is that effective, and if so, in which scenario? (describe a concrete case.)
   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).

3. Suppose you have an exoskeleton for upper-arm rehabilitation such as the one in the figure below (FLOAT). Can such a device provide somatosensory feedback in principle? What sensors / actuators would it need in order to provide it?
   All exoskeletons provide somatosensory feedback due to their nature: the user perceives immediately the resistance offered by the structure of the exoskeleton. 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.

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Question #2: (35%)

Text of the question. (Not hidden.)

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 Hudgin's 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! => 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
```

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 is 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)

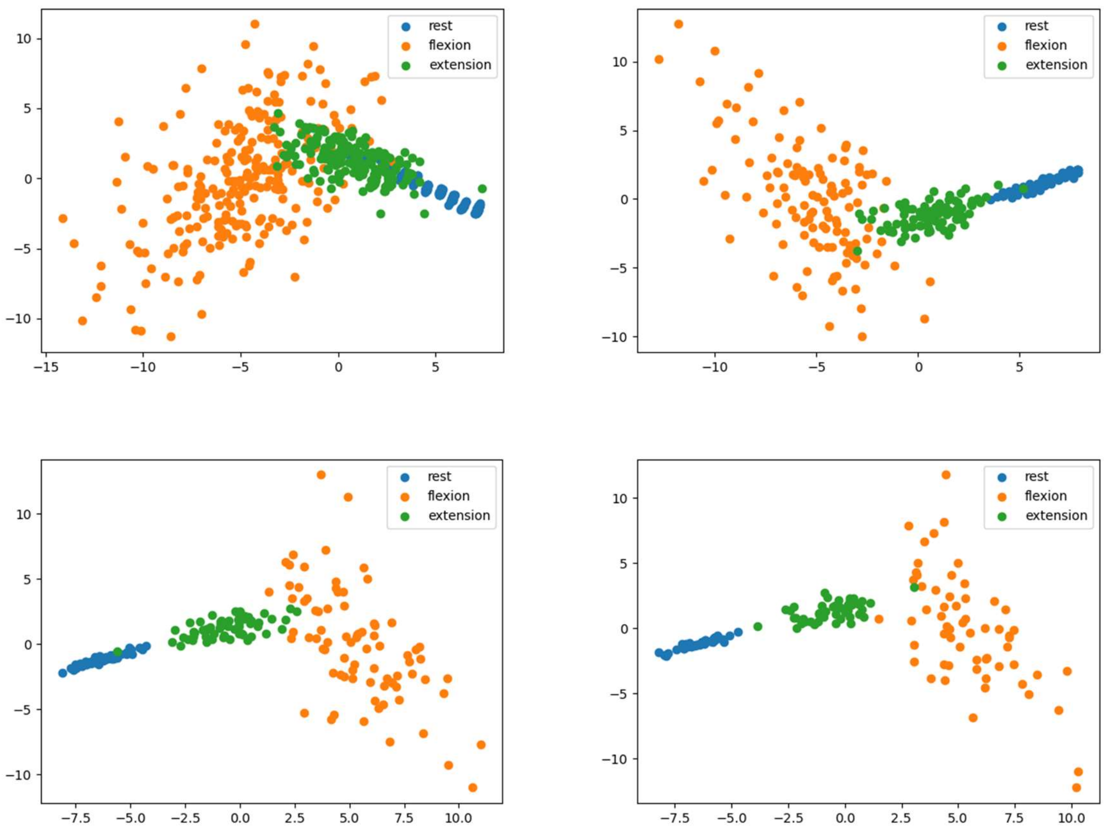

Figure 1 - PCAs

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**

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Question #3: (35%)

Text of the question. (Not hidden.)

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 z-axis S_z of the local sensor frame S points in the direction depicted below (Figure 2). Furthermore, assume that the kinematic chain (Figure 3) 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:

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

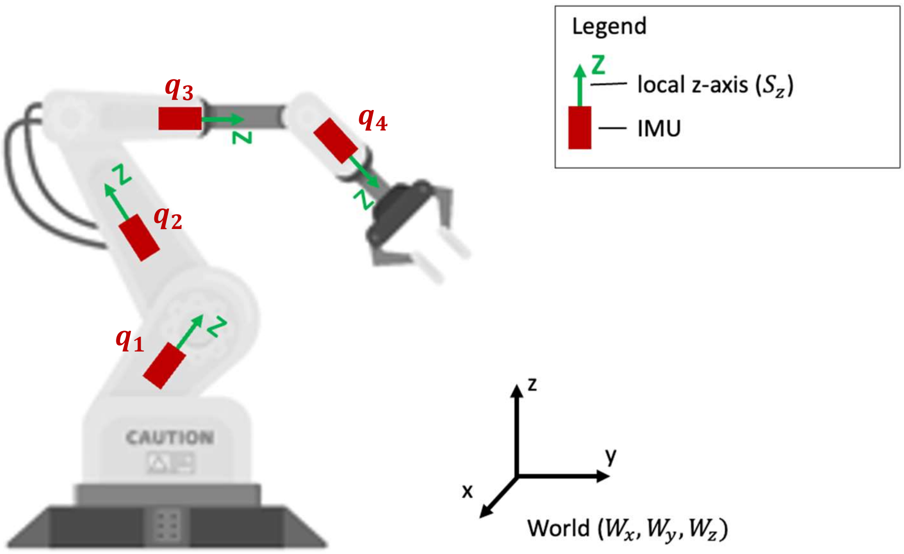


Figure 2 - IMU placement

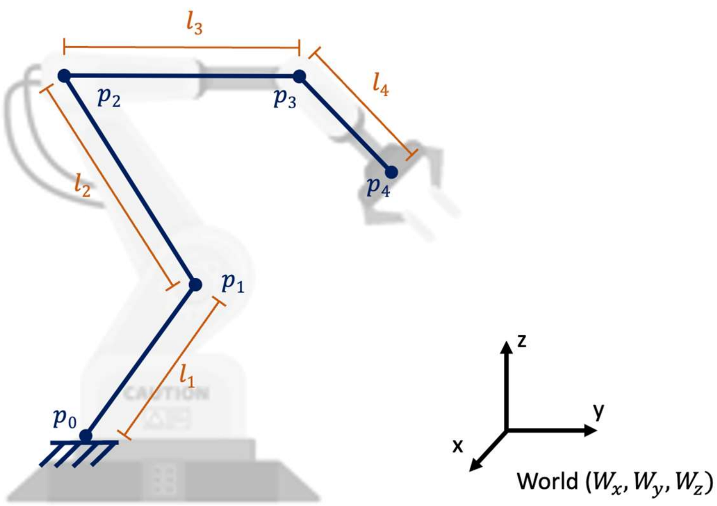


Figure 3 – kinematic chain

3.1 Solution

5

Solution 3.1

1. Define pure quaternions from ls:

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

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

2. Calculate p_4 in the world frame

9 $[q_{p_1} = q_1\ q_{l_1}\ q_1^*]$ not necessary

$$q_{p_4} = q_1 q_{l_1} q_1^* + q_2 q_{l_2} q_2^*$$

3 $$+ q_3 q_{l_3} q_3^* + q_4 q_{l_4} q_4^*$$

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

3 3. Distance

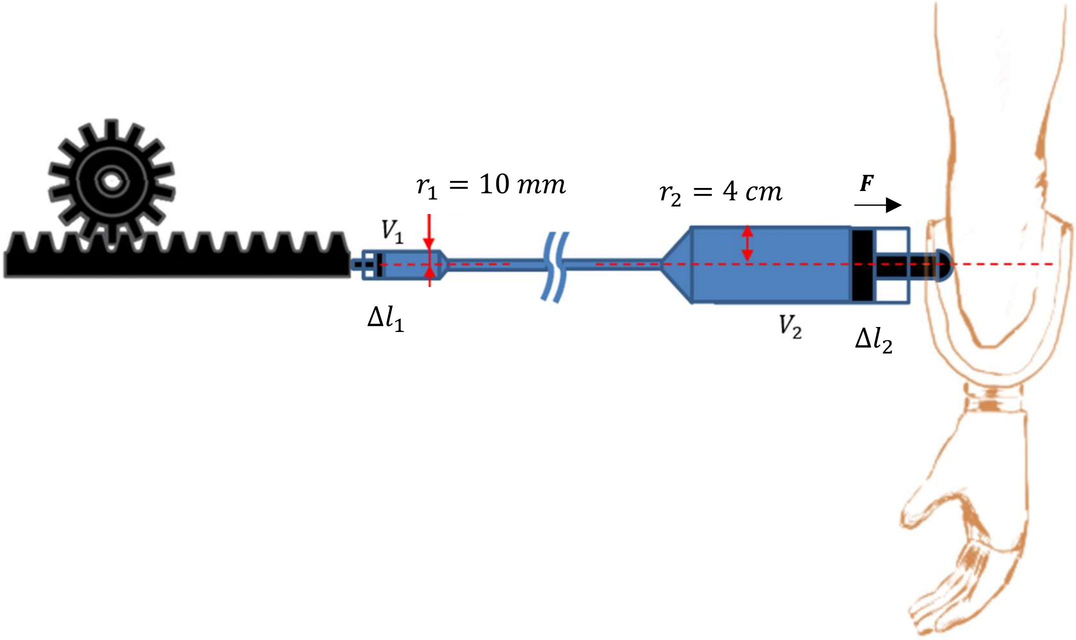
$$\vec{d} = \vec{p}_4 - \underbrace{\vec{p}_0}_{(0\,0\,0)}$$

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

Text of the question. (Not hidden.)

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 $3\ N$. 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

$$\Delta l_2 = 3\ \mathrm{N} \cdot 0.1\ \mathrm{cm/N} = 0.3\ \mathrm{cm}$$

Calculate Δl_1: 10

$$\Delta V_1 = \Delta V_2$$

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

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

$$\Delta l_1 = 0.016\ \mathrm{m} = 48\ \mathrm{mm}$$