Estimating Stiffness & Required Grasp Force at First Contact in a Prosthetic Hand using Vibrational Information

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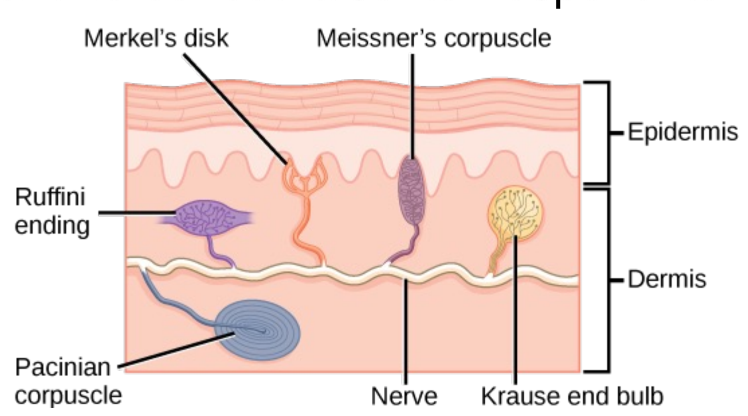
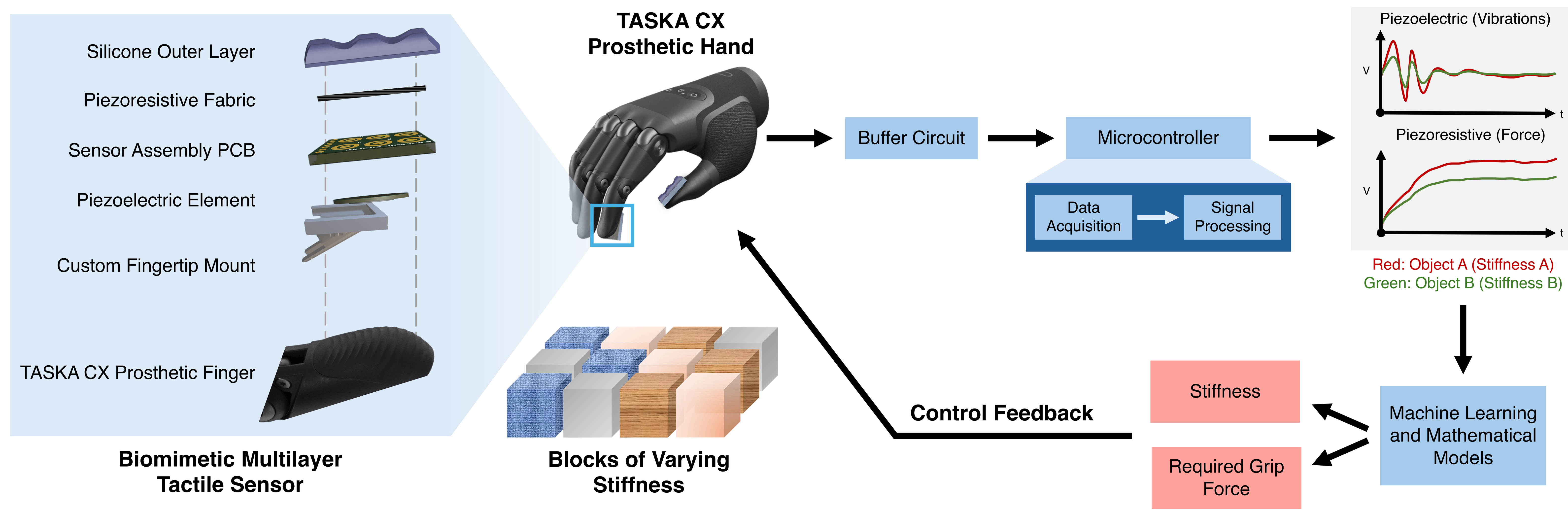
Background

- Current studies on sensory feedback in prosthetics primarily **concentrate on force sensing** and its conveyance to the user.
- However, the skin houses **various types of mechanoreceptors** designed not only to sense constant force but also to respond to vibrations.
- **Vibrational sensing** and feedback in prosthetics are **significantly understudied**, particularly in the context of prosthetic grasps.
- Vibrations upon impact are crucial because they are **detected more quickly at the initial contact** than force sensing.
- In this study, our objective is to **showcase the potential of vibrational sensing in prosthetics** and to compare it with traditional force sensing methodologies.



Distribution of skin mechanoreceptors.
(Adapted from www.lumenlearning.com)

Methodology



Motivation and Aims

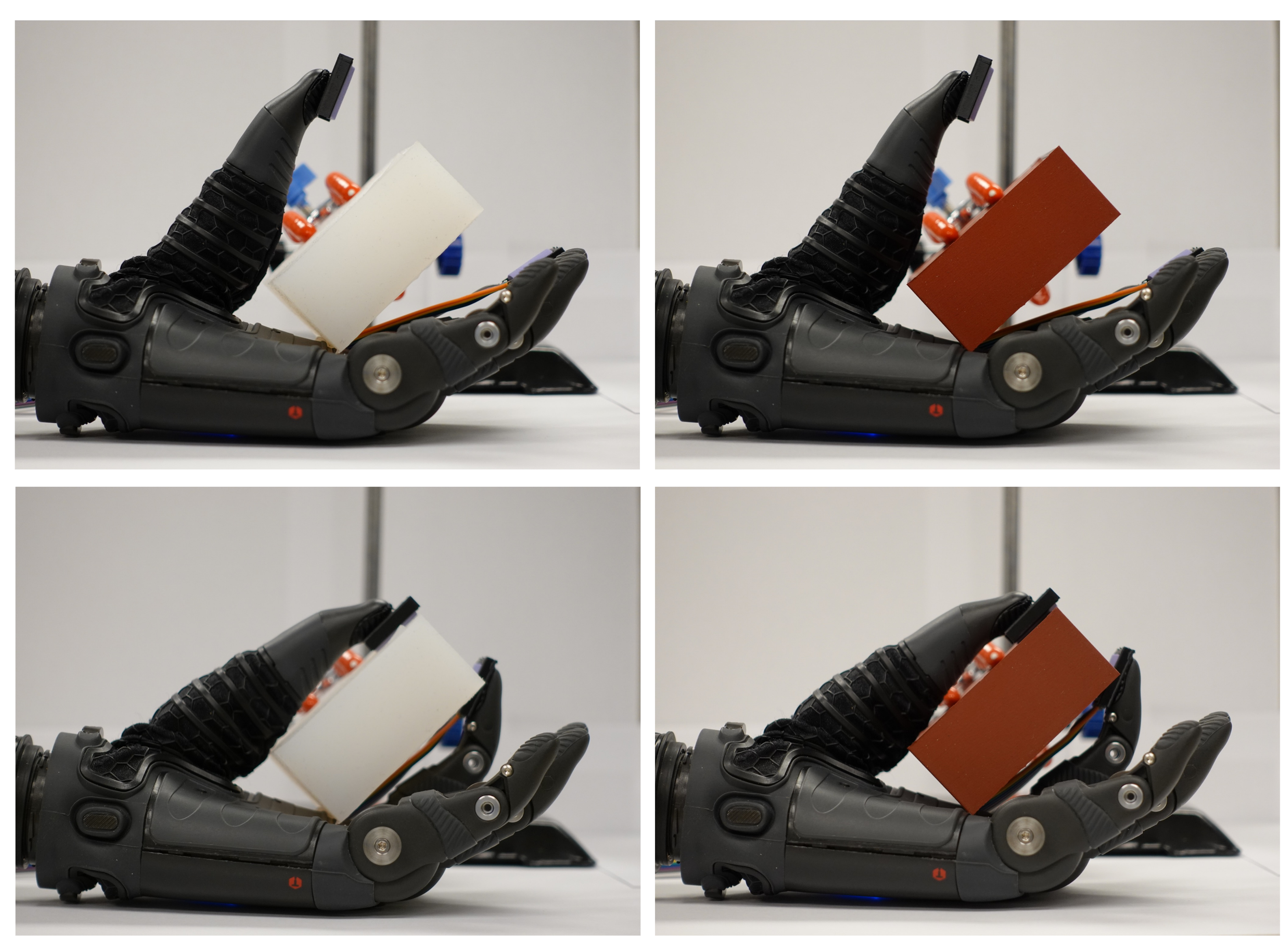
What should be encoded?	**How should it be processed?**
Force information? Vibrational information? Force + Vibrational Information?	Amplitude proportional? Frequency proportional? Peak detection?
Why is it important?	**When is one better?**
What can it tell us? Stiffness? Required Grip Force?	When is the input dominant in task? Can we switch between sensors to achieve optimum performance?

- The role of **dynamic sensing mechanoreceptors** in daily tasks is **understudied** and **rarely considered in prosthetic design**.
- This study aims to highlight the **importance of vibration sensing in everyday activities**, and advocate for the **integration** of vibration sensing **capabilities in prosthetics** to enhance their functionality.
- **Human grasps are asymmetrical**; for example, during a pinch grip, one finger contacts the object before the other.
- The **initial finger contact** can provide **information about the object's properties**, allowing **adjustments** in control system parameters for **optimal grip force**.
- We hypothesize that **piezoelectric and piezoresistive** sensors can be used to **characterize** object properties based on this **initial contact information.**
- **Machine learning and mathematical models** could be used for prediction tasks.

Scan for working video of the experimental setup!

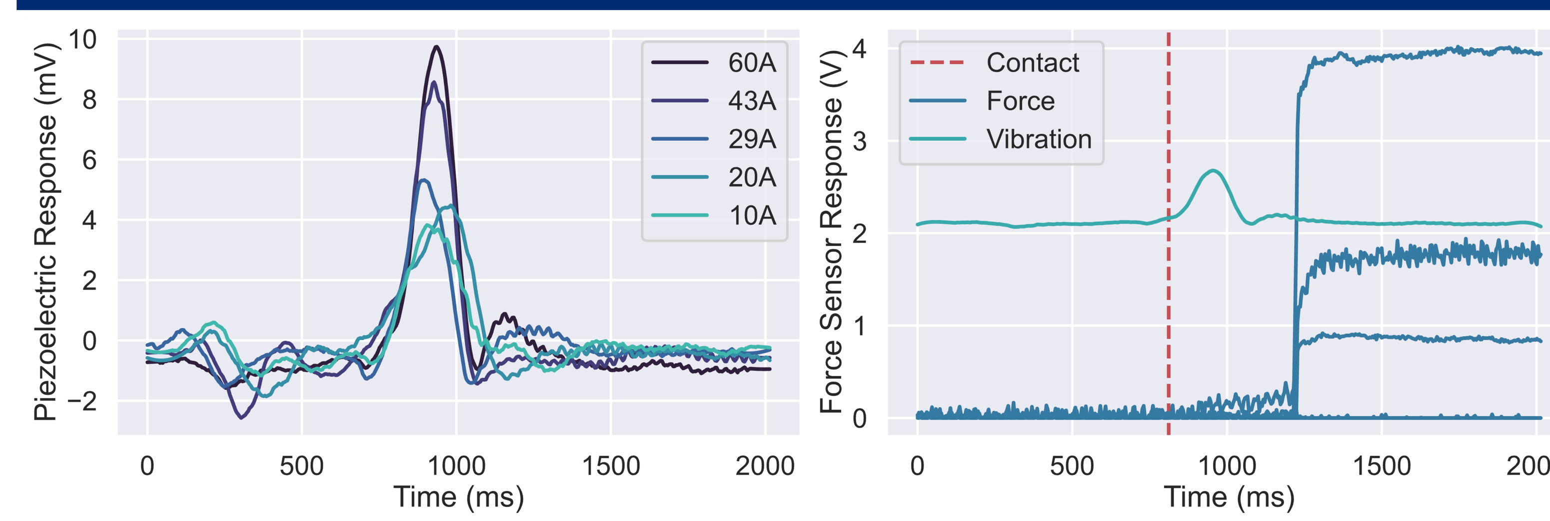
Experimental Setup

- The **TASKA CX Hand** is programmed to **pinch silicone blocks** using a **constant force**, regulated through speed and motor current.
- These silicone blocks **vary in stiffness** (Shore 00/A) and are grasped in a pinch grip using the index and thumb finger.
- Data from **6 piezoresistive force sensors** and **1 piezoelectric vibration sensor** are recorded at ~200Hz.
- **100 individual pinches** are collected for each block for model training.
- The exact **moment of contact** is verified using electrical contact strips and high-speed videography.



Pinching task for shore hardness 10A *(left)* **and 60A** *(right)*.

Preliminary Results



Piezoelectric sensor outputs at impact for various stiffnesses *(left)*; **and the combined piezoresistive and piezoelectric** (amplified for visualization) **output for SH 60A** *(right)*.

- In the plot on the left, we observe that the **amplitude response of piezoelectric disk is proportional to the stiffness of the block,** indicating that there is the **potential to both classify and regress** object properties using this information.
- In the plot on the right, we see that the **onset of the piezoelectric response is 12ms (3δ) after the moment of contact**, whereas a **shift in force is seen 412ms later**.
- The plot, when observed with a slow-motion video of the prosthetic hand, confirms the intuition that **force is applied only when the second finger makes contact**.

Next Steps

- Building **machine learning and mathematical models** to **classify and predict object stiffness** using piezoelectric and piezoresistive sensor data.
- Developing a **fast, robust closed-loop system** that utilizes initial contact vibration information to **control the final force exerted by the prosthetic hand** during a grasp.
- Sensor **improvements for sensitivity and reliability**.