A Haptic Exploration and Surface Classification of Objects with Four Typical Surface Properties

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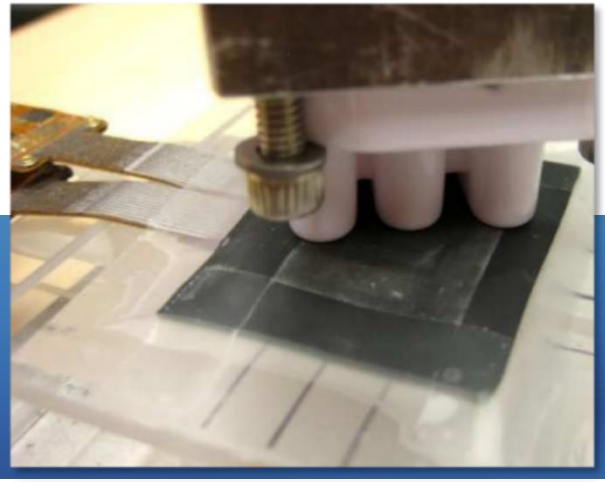
Background: Surface Exploration Surface features

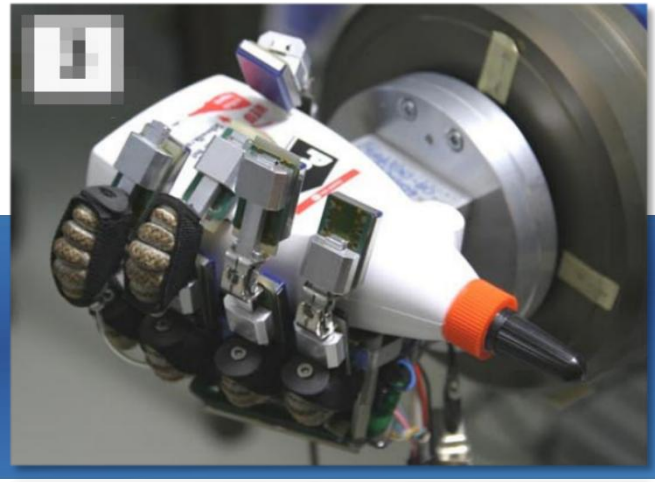
Factors for identifying the specific properties of object:

local contact geometry and the sensation of touching.

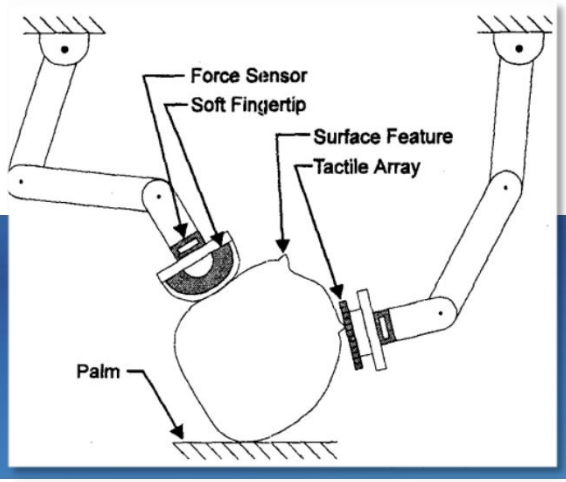


Tactile Sensor

Tactile Robots



Tactile Robotic Grasping



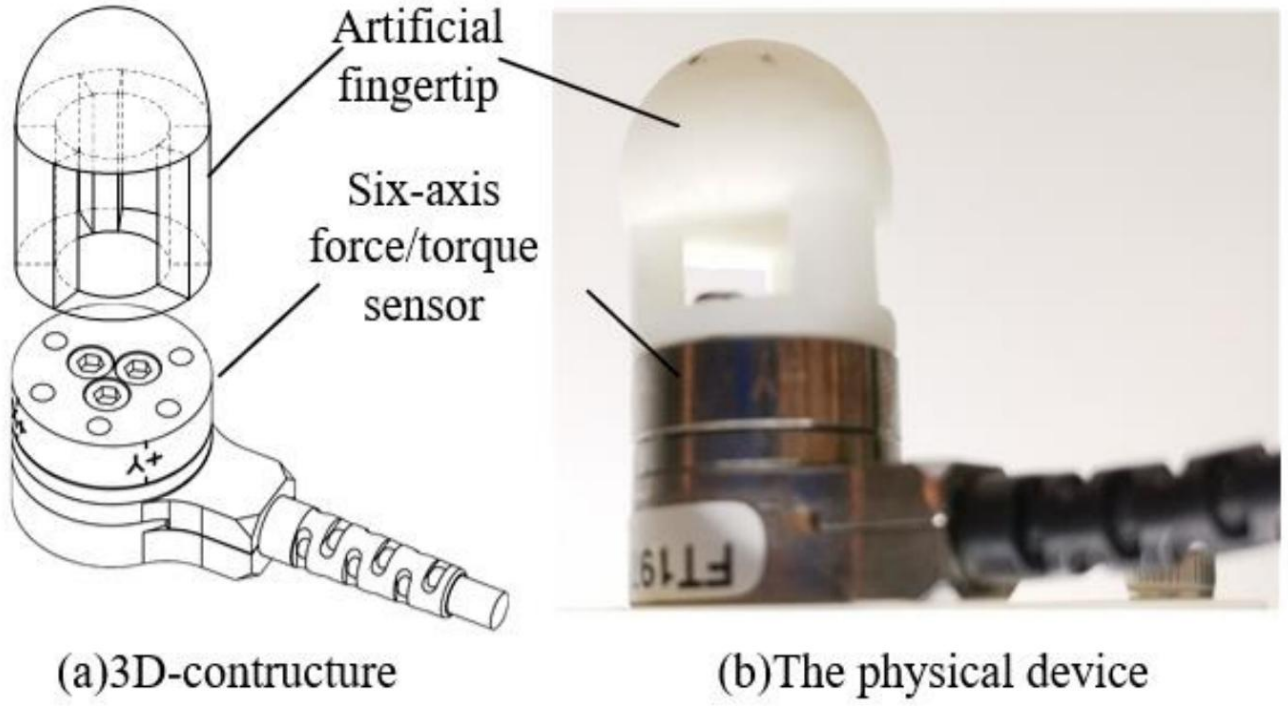
Surface Exploration in Robotics

System Setup

Ⅰ. The Design of the Fingertip

Ⅱ. The Tactile Information Dataset

Design of the contact fingertip



(a)3D-contructure (b)The physical device

Structure of Contact fingertip

- 6-axis transducer on the fingertip.
  (ATI Nano17 force/torque sensor)
- Hemispherical hat.

Hollow out extension structure

- Increasing the length of the contact fingertip.
- Expanding the detection range.

Dedicated robotic fingertip equipped with a mini force sensor

System Setup

Ⅰ. The Design of the Fingertip

Ⅱ. The Tactile Information Dataset

Establishment of the Dataset

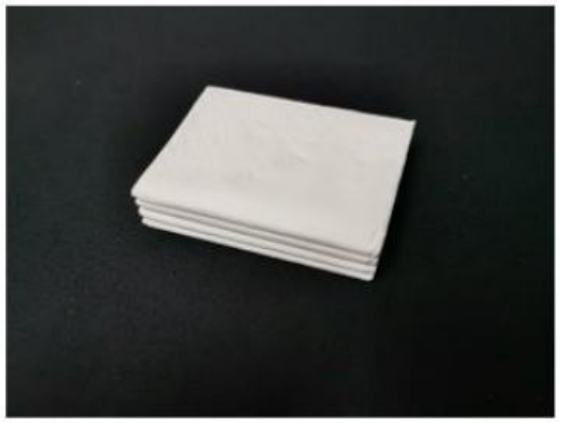
- **Collected by our tactile sensing fingertip.**
- **2000 data records obtained by touching the four objects.**
- **1000 records for training, 1000 for testing.**

Labels of Four Objects

Type of object	Labels
Tissue packaging	Soft-smooth
Sponge cushion	Soft-rough
Acrylic board	Hard-smooth
Wooden board	Hard-rough

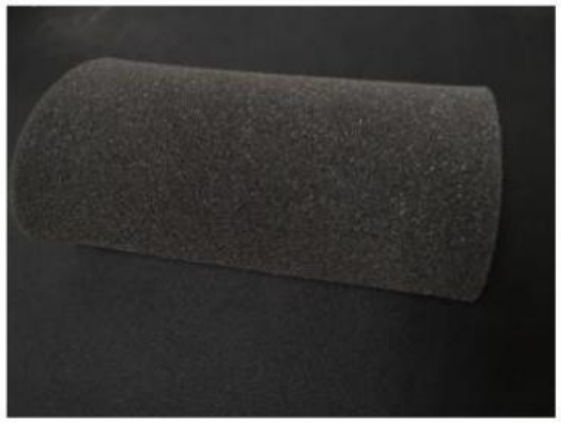
Example images of the four object types in our Tactile Information Dataset

(a)Acrylic board



(b)Tissue packaging

(c)Wooden board



(d)Sponge cushion

Surface-following Algorithm

I. Acquisition and Processing of Tactile Information

Contact Equilibrium System Equation

- **Computing the contact location according to the force/torque measured.**

Contact Sensing Information Estimating

- **Levenberg-Marquardt Algorithm (LMA).**
- **Mean error：0.25mm.**

The contact equilibrium system equation:

$$q^T = (x, y, z, p)^T$$

$$g^T(q) = (g_1(q), g_2(q), g_3(q), g_4(q))^T$$

$$g^T(q) = \begin{cases} p\nabla U_x - f_y z + f_z y - m_x \\ p\nabla U_y - f_z x + f_x z - m_y \\ p\nabla U_z - f_x y + f_y x - m_z \\ U(x, y, z) \end{cases}$$

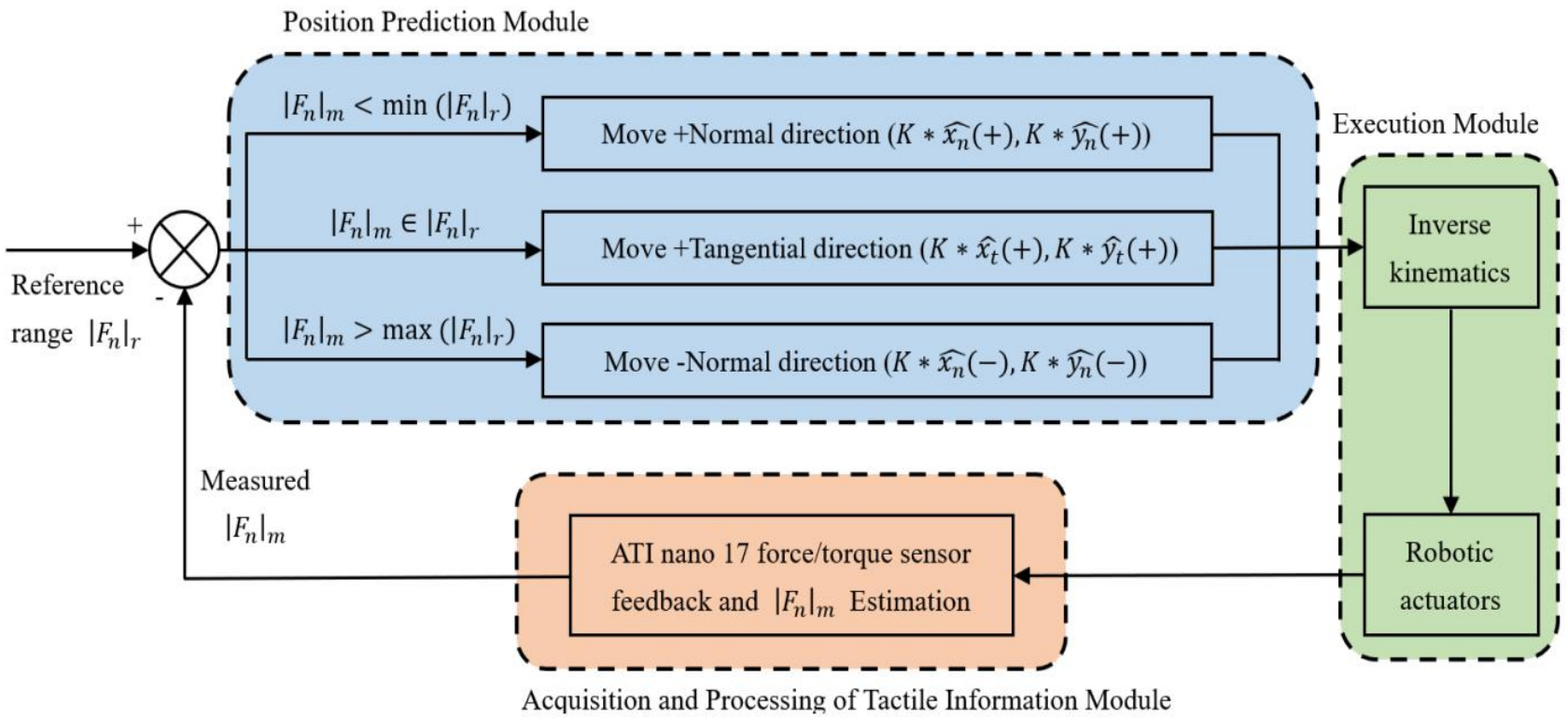
Fingertip marker with three groups of dots:

Accuracy validation of the LMA

Groups	Distance from Caliper	Distance from Sensor	Error
1	9.87mm	9.72mm	0.15mm
2	14.79mm	14.98mm	-0.19mm
3	14.13mm	14.53mm	-0.40mm

Surface-following Algorithm

II. Efficient Surface-Following Algorithm



Position Prediction Module

- Determining the surface tracking direction of the artificial fingertip.

Execution Module

- Controling the robotic arm to change the position of fingertip.

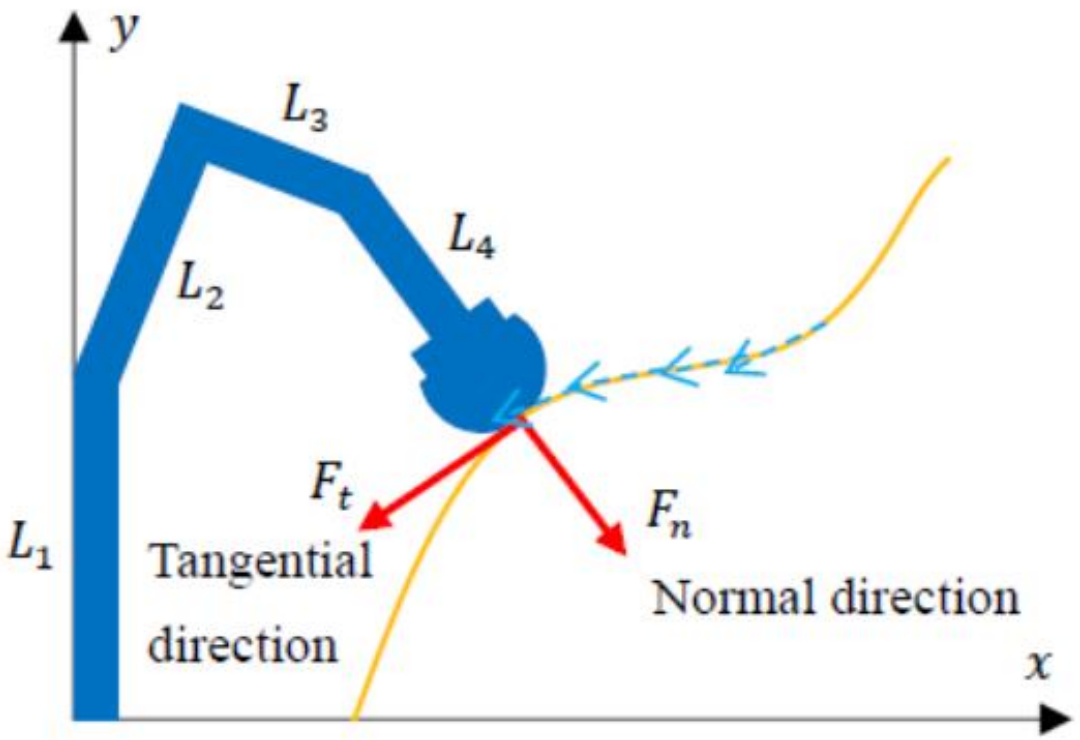
Acquisition & Processing Module

- Collecting the force/torque information.
- Estimating the tangential force and the normal force.

Surface-following Algorithm

II. Efficient Surface-Following Algorithm

Predictive surface contour tracking of an unknown object:



$$\begin{cases} if \ |F_n| < \min(|F_r|), \text{ then move + direction } F_n \\ if \ |F_n| \in range(|F_r|), \text{ then move + direction } F_t \\ if \ |F_n| > \max(|F_r|), \text{ then move - direction } F_n \end{cases}$$

$$x_{n+1} = x_n + K * \hat{x}_t$$

$$y_{n+1} = y_n + K * \hat{y}_t$$

$$\hat{x}_t = \frac{F_{tx}}{\|F_t\|} \quad \hat{y}_t = \frac{F_{ty}}{\|F_t\|}$$

Experiments

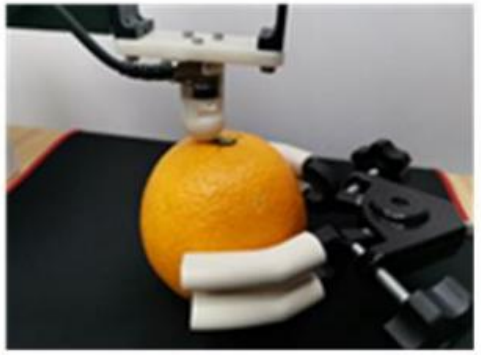
Ⅰ. **Surface Haptic Exploration of Several Objects**

Ⅱ. The Friction Coefficient of the Object's Surface

Ⅲ. Tactile Recognition Algorithm Based on a Feedforward Neural Network

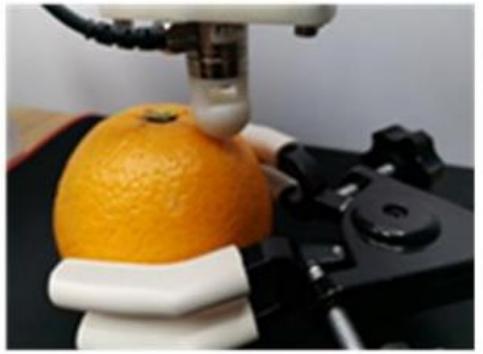
The procedure of the contour following on an orange using the contact sensing fingertip based on the proposed control algorithm

(a)

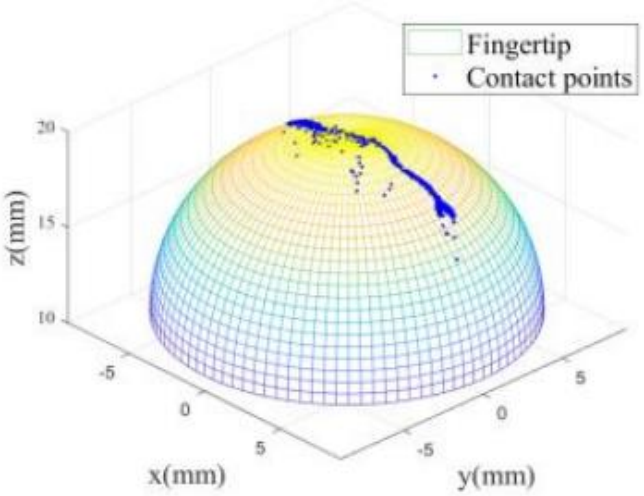


(b)

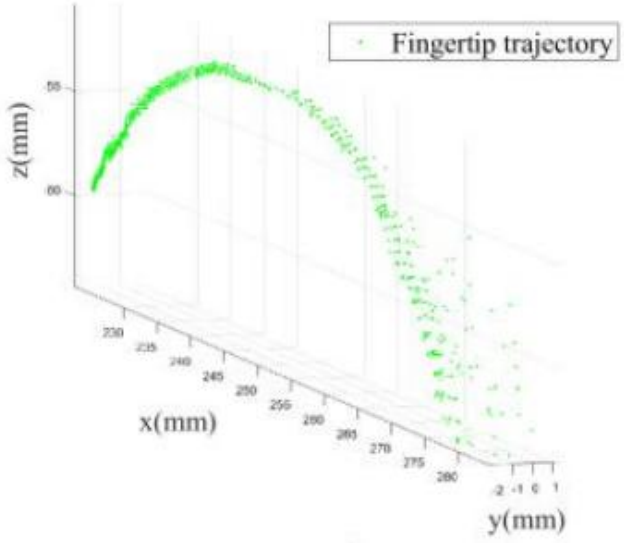
(c)



(d)



(e)



(f)

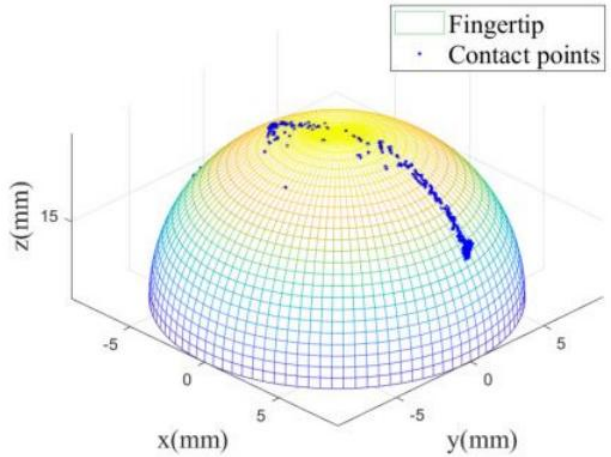
Experiments

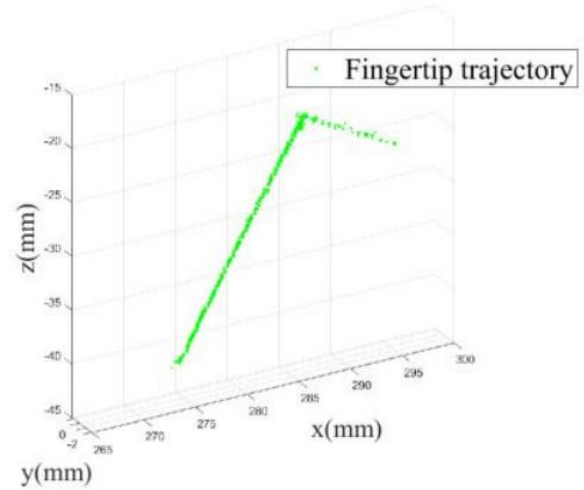
Ⅰ. **Surface Haptic Exploration of Several Objects**

Ⅱ. The Friction Coefficient of the Object's Surface

Ⅲ. Tactile Recognition Algorithm Based on a Feedforward Neural Network

Exploring the feasibility of the surface-following algorithm on surface with discontinuous curvatures.





Experiments

Ⅰ. Surface Haptic Exploration of Several Objects

Ⅱ. The Friction Coefficient of the Object's Surface

Ⅲ. Tactile Recognition Algorithm Based on a Feedforward Neural Network

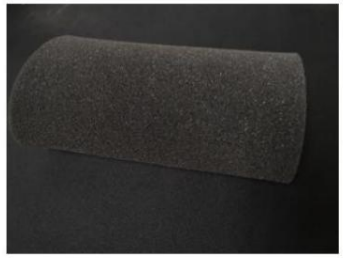
The friction coefficient f can be computed as: $f = \left| \frac{F_t}{F_n} \right|$

Type of object	Average friction coefficient
Tissue packaging	0.097
Sponge cushion	0.361
Acrylic board	0.035
Wooden board	0.833

(a)Acrylic board

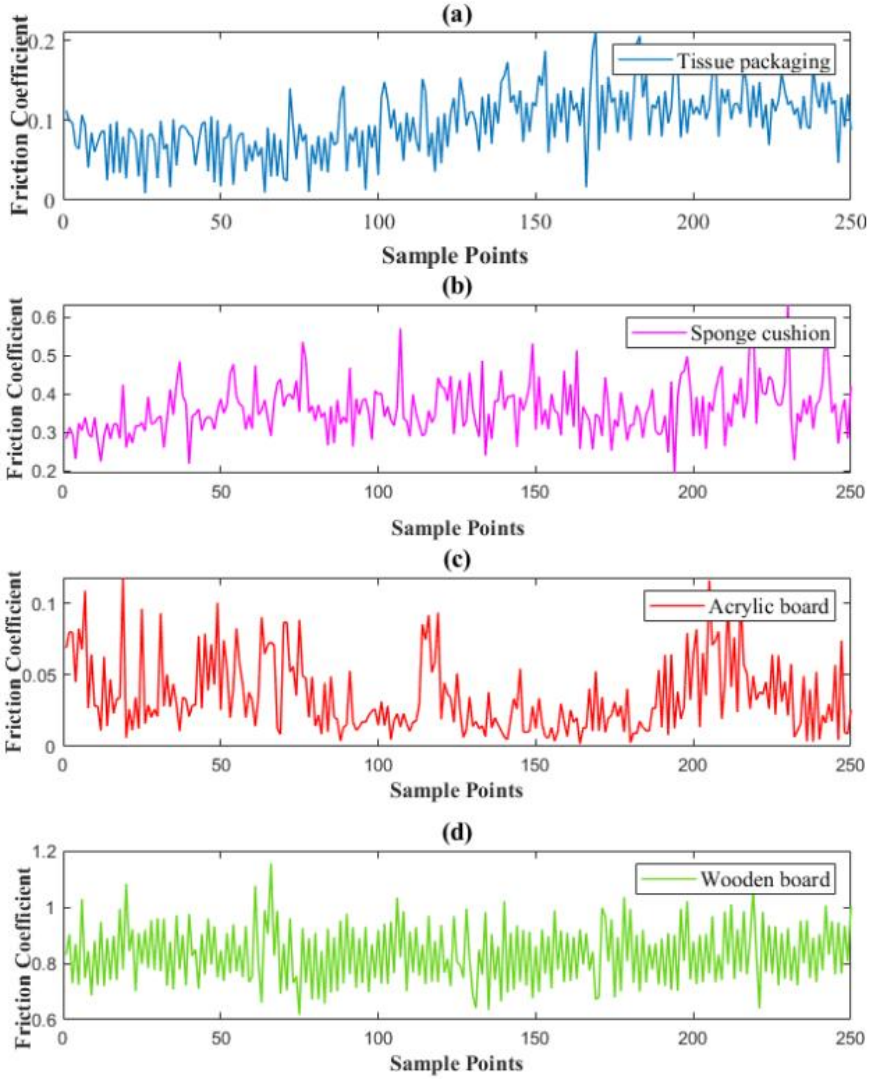
(b)Tissue packaging

(c)Wooden board



(d)Sponge cushion

The friction coefficient of the detected objects



Experiments

Ⅰ. Surface Haptic Exploration of Several Objects

Ⅱ. The Friction Coefficient of the Object's Surface

Ⅲ. Tactile Recognition Algorithm Based on a Feedforward Neural Network

The classification boundary is obtained by neural network. Most of the objects are correctly divided. Some outliers exist due to the measurement error.

Input:

Tangential Force and Normal Force

10 neurons

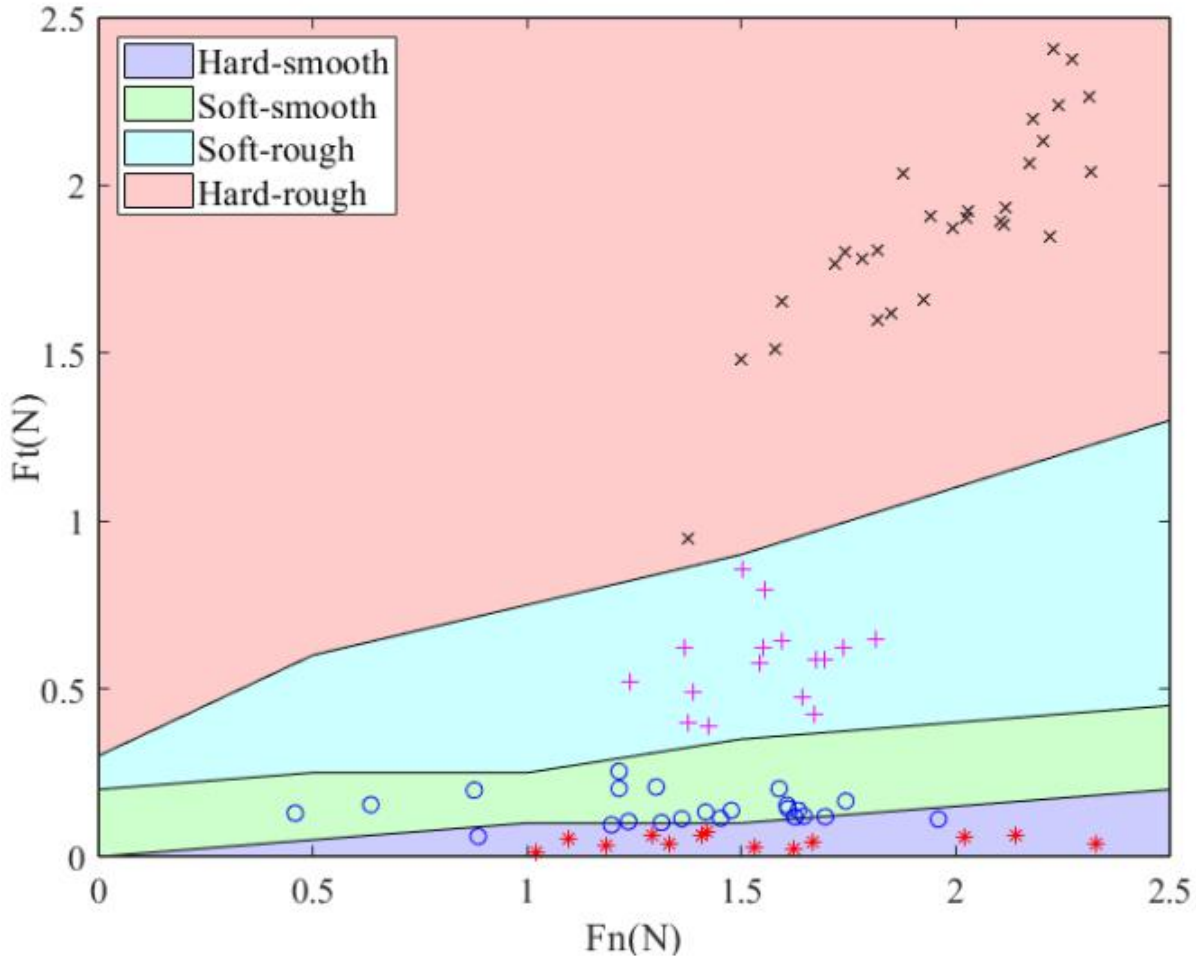
Sigmoid Function

Output:

Probabilities for the four adjectives

Type of object	Accuracy	Average accuracy
Soft-smooth	86.0%	90.2%
Soft-rough	92.2%	
Hard-smooth	90.0%	
Hard-rough	96.3%	

The classification test result of the trained model



Discussion and Future Work

I. Conclusion

- Design of an artificial fingertip.
- Experimental validation of the artificial fingertip.

II. Future Work

- Utilizing more detailed features.
- Enhancing the efficiency of surface tracking algorithms

Thanks !

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