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Operator-Avatar Texture Feedback Approach using Hand-eye Camera and Force Sensor

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***Abstract*— This paper introduces an operator-avatar texture interaction method using a hand-eye camera and force sensor at the robot fingertip. When performing a task using an avatar robot, the operator relies on information collected by the robot in a remote environment to determine the next behavior of the robot. Therefore, it is crucial to improve the interaction quality between the avatar and the operator. To enhance the interaction quality, the proposed method utilizes visual and force information. This method successfully conveyed the object surface texture to the operator with distinguishable vibration patterns.**

I. Introduction

Robots are beneficial in various fields by providing remote access to hazardous tasks. Therefore, improving the performance of the interaction between the avatar robot and the operator is crucial, as an accurate understanding of the condition and capabilities of the robot is essential for directing its subsequent actions. The incorporation of texture perception in teleoperation can enhance the sense of presence and immersion when making decisions through the robot. Specifically, when manipulating objects or exploring unfamiliar surfaces using the robot hand, the sense of texture can facilitate intuitive interactions, while simultaneously enabling the remote operator to acquire new information from areas beyond the visual field. The ANA Avatar XPRIZE Finals took place in Long Beach, California, USA, in November 2022. The competition aimed to develop an avatar system capable of conveying real-time human presence to remote locations. The contest included ten objectives, with the final objective requiring remote operators to distinguish the texture of the surface to select and remove a rough stone from a box covered with a dark cloth. To achieve the final objective, this paper proposes a simple and reliable method for surface roughness distinction through teleoperation. Previous attempts at remote texture feedback methods have been introduced in [1] and [2]. A piezoelectric sensor was mounted on a fingertip to collect signals while performing an exploratory movement [1]. However, this sensing method has some limitations. It requires mechanical contact between the sensor and the testing surface, and the entire acquisition process mandates constant sliding speed. A wearable tactile feedback system that employs three pairs of independently rotating micromotors has been introduced [2]. The system was capable of transferring the surface texture to the operator but lacked a solution for detecting and exploiting this information. Thus, this system was deemed unsuitable for use in the Avatar XPRIZE Finals.

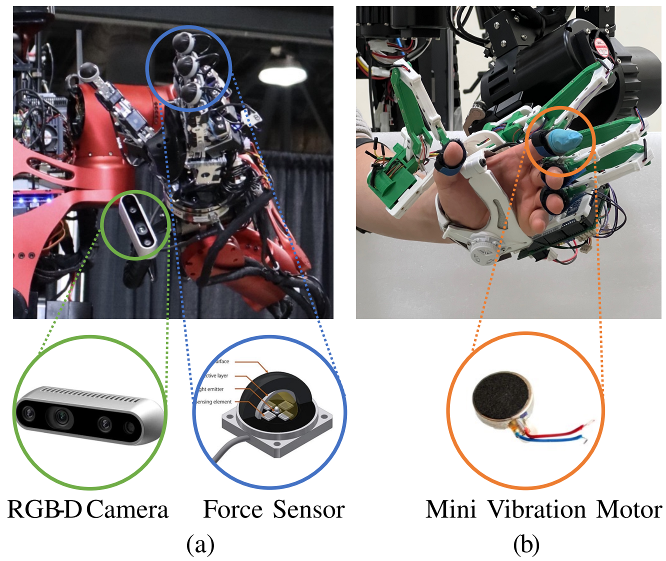

Fig. 1: Avatar robot and operator glove systems for conveying surface texture signal. (a): Object detection system of the avatar robot. (b): Tactile feedback system of the operator haptics.

The proposed method enhances and integrates the texture detection and feedback methods by implementing additional sensors on the avatar robot wrist and feedback device on the haptic glove.

II. System Architecture

The avatar system includes an on-site avatar robot and operator haptics. The avatar robot used in the experiment is the TOCABI humanoid robot [3]. As illustrated in Fig. 1 (a), an Intel D435i RGB-D camera is mounted on the left wrist of the avatar robot hand, and Optoforce force sensors are attached to the fingertip of the robot. The wrist, where the camera is attached, is a kinematically safe area when grasping an object below the elbow. The operator haptics is

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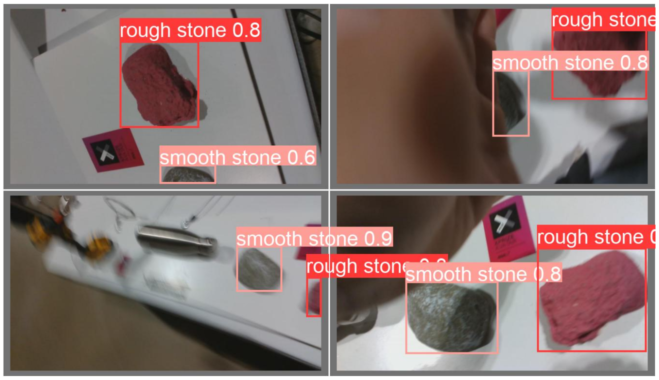

Fig. 2: Snapshots of prediction. Red and pink boxes are bounding boxes of recognized objects. Red and pink colors indicate rough and smooth stones, respectively. The number following the class name is the certainty of the class.

capable of receiving the force feedback and is equipped with a glove at the end, as shown in Fig. 1 (b). The gloves have vibration motors for force and texture feedback. In particular, the left glove includes a blue finger cover that can transfer the fingertip feedback. To drive the vibration motor in the glove, an optocoupler PC847 for circuit isolation and a transistor ULN2803AFWG for signal amplification were used.

III. Object Surface Texture Haptic Feedback

The system conveys object surface texture signals to the operator based on the image obtained from the RGB-D camera and the magnitude of the force sensor. A YOLOv5 algorithm [4] was employed to accurately detect and classify objects in the images. In order to enhance the performance of the neural network, a dataset was curated and labeled according to the texture classes. Moreover, dark environments were also considered in dataset acquisitions. Depth images, however, were omitted as it is difficult to distinguish surface data owing to the noise level. Therefore, only RGB images were used in the evaluation. Further, the dataset was augmented using a variety of image transformations, including changes in color, exposure, and the addition of noise. These techniques enabled the model to learn about texture in a more robust and comprehensive manner. A total of 445 labeled images were captured by the RGB-D camera. Two classes, smooth and rough stone, were used for classification. As shown in Fig. 2, the algorithm robustly detected and classified the objects and their surfaces. The model performance is listed in Table I.

TABLE I: Classification Performance of Model (%)

Metric	Value
Precision	100.0
Recall	98.7
mAP_{50}	99.5
$mAP_{50:95}$	82.1

The proposed method is illustrated in Fig. 3. When the pressure measured by the force sensor attached to the finger of the avatar robot exceeded a predefined threshold, it was

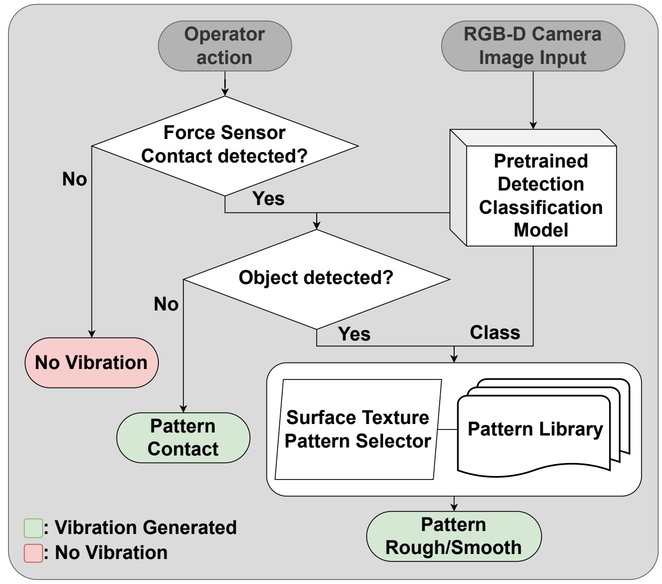

Fig. 3: Pattern selection algorithm using RGB-D camera and force sensor.

considered to be in contact with the object. In the experiments, 0.3 N was used as the threshold. Vibration patterns were used to transfer the sense of the texture. The most ideal way to obtain telepresence is transmitting the measured surface texture without information loss. Previous study [1] showed that a dominant signal occurred at 450 Hz in the FFT output of a surface with a groove and ridge width of 0.2 mm. However, conveying such high-frequency texture signals was difficult due to the large rotor inertia of the vibration motor. To solve this problem, vibration patterns were created by combining discrete waves from 0.5 to 10 Hz. Higher frequencies were used for rough surfaces and lower frequencies were used for smooth surfaces. The amplitude of the pattern is proportional to the measured robot fingertip force. If an object is detected and the contact exists, a pattern for the object class is chosen. The type of vibration is chosen based on the object closest to the center of the palm of the robot hand. If there is contact detection but without a classified object, low-amplitude constant vibration feedback was used to notify the contact. When the object suddenly disappears on account of the adjustments of the hand, the last detected state is maintained as long as the pressure of the force sensor is maintained.

IV. Conclusion

In this paper, a texture-transferring method was presented for improved feedback to the remote operator, using a visual sensor attached to the wrist of the avatar robot and a force sensor on the fingertip. This technique allows the operator to perceive differences in surface texture, even when relying on low-cost vibrators that may not be able to transmit high-frequency signals. The results demonstrate the feasibility of accurately distinguishing between two texture classes, namely rough and smooth, paving the way for expanding the classification range with additional classes.

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