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Demonstration of a Hybrid Haptic Device and AI-Driven Car Door Profile Generation System

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***Abstract*— We present a hybrid haptic device capable of delivering high-torque kinesthetic feedback for realistic car door interaction, coupled with an AI-driven system that generates personalized torque profiles from user-defined haptic attributes. The hardware combines a direct-drive servo motor and an MR brake to render active and passive torque components derived from real-world measurements. Complementing the hardware, a deep learning-based profile generation system enables users to specify high-level haptic attributes, from which a predicted torque profile is generated and rendered in real time. This demonstration allows participants to physically interact with realistic door behaviors and experience personalized haptic feedback through intuitive, attribute-based control.**

I. Introduction

Existing haptic devices struggle to replicate the high torques and friction needed for realistic car door simulation. We address this by developing a hybrid haptic device that separates active and passive torque rendering using a servo motor and an MR brake. To support personalization, a deep learning system predicts torque profiles from user-defined haptic attributes, enabling rapid design exploration without manual tuning.

II. System Overview

This section first describes the hardware design of the developed car door simulator, followed by the procedure used for user-preferred profile generation(Overview in Figure 1).

A. Hardware Design of the Car Door Simulaor

The hybrid haptic device consists of a 1-DoF rotational arm driven by a servo motor (up to 54 Nm) and an MR Brake (up to 50 Nm), integrated with a real car door handle (see Figure 1(d)). Force/torque profiles are separated into active and passive components and rendered using hybrid impedance control at a 1 kHz loop rate. Physical mass matching ensures realistic inertia without instability. The system delivers lifelike sensations of door opening, hinge snapping, friction, and gravitational pull during closure.

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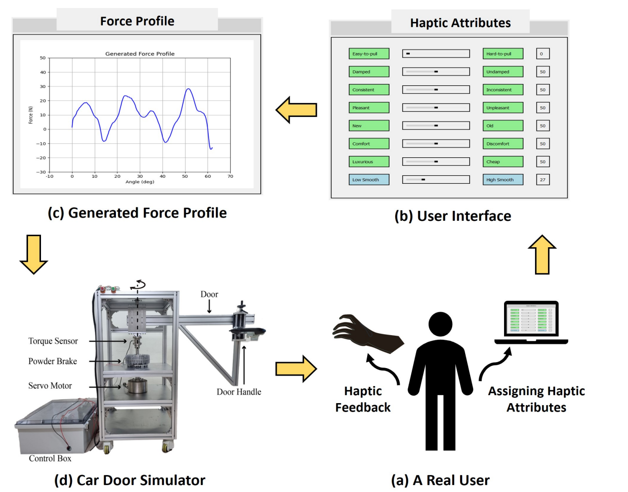

Fig. 1. The user assigns preferred haptic attributes through an interface. A generative AI model predicts the corresponding force profile, which is transmitted to the car door simulator for rendering and interaction.

B. Force Profile Generation from Haptic Attributes

The system was developed in multiple stages. First, force and torque profiles were recorded from real car door interactions using torque and position sensors. These profiles were then expanded through controlled augmentation and rendered on a car door simulator, enabling users to experience diverse door behaviors. Users rated these profiles on a 0–100 scale across perceptual attributes such as ease of pull, luxury, pleasantness, damping, consistency, novelty, and comfort. A hybrid CNN-LSTM autoencoder was trained to predict torque profiles from user-defined attribute values. A GUI was also developed, allowing real-time haptic feedback generation via adjustable sliders (see Figure 1).

III. DESCRIPTION OF THE DEMONSTRATION

During the demonstration, participants will first experience pre-defined car door profiles rendered with high-torque, kinesthetic feedback. They will then use the AI-driven GUI to specify preferred attribute values (see Sec. II-B), and feel the generated torque profiles through the device immediately. A real-time visualization will display torque signals, attribute values, and model predictions, illustrating the seamless transition from perceptual intent to mechanical experience.