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RESEARCH ARTICLE

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Elevating haptic interfaces: Dual-rate sampling and field programmable gate array implementation for multi-degree-of-freedom performance enhancement

Majid Koul[1] | **Suhail Khosa**[2] | **Babar Ahmad**[2]

[1]Mechanical Engineering, Islamic University of Science and Technology, Kashmir, Jammu and Kashmir, India

[2]Mechanical Engineering, National Institute of Technology Srinagar, Jammu and Kashmir, India

Correspondence
Majid Koul, Mechanical Engineering, Islamic University of Science and Technology, Kashmir, India.
Email: majid.koul@iust.ac.in

Abstract

In this work, our primary focus centered on exploring the adaptability of the dual-rate sampling scheme proposed earlier to enhance the performance of multi-degree-of-freedom (multi-DOF) impedance-based haptic interfaces. The scheme employed independent sampling rates in a haptics controller, effectively mitigating the issue of reduced Z-width at higher sampling rates. A key aspect of our investigation was the intricate implementation of the dual-rate sampling scheme on a field programmable gate array (FPGA). This implementation on a logic hardware FPGA was challenging and led to the effective comparison of the uniform-rate and dual-rate sampling schemes of the multi-DOF haptic controller. We used an in-house developed two-DOF pantograph as the haptic interface and an FPGA for implementing the controller strategy. FPGA-based implementation presented challenges that were vital in testing controller performances at higher sampling rates. Virtual wall experiments were conducted to determine the stable and unstable interactions with the virtual wall. To complement the experimental results, we simulated the haptics force law for multi-DOF system on Simulink/MATLAB. Notably, the dual-rate sampling approach maintained the Z-width of the two-DOF haptic interface, even at higher controller sampling rates, distinguishing it from the conventional two-DOF uniform-rate control scheme. For example, employing a dual-rate sampling combination of 20–2 kHz consistently ensured the stable rendering of a maximum virtual stiffness of approximately 700 N/mm and maintained a reliable virtual damping range spanning from 0 to 5 Ns/mm. In contrast, the 20 kHz uniform-rate sampling approach failed to ensure interface stability in the presence of virtual damping, ultimately resulting in the unsuccessful implementation of any virtual stiffness at higher sampling rates. This work, therefore, establishes the potential of dual-rate sampling in the realm of haptic technology, with practical applications in multi-DOF systems.

KEYWORDS

control FPGA, haptic device, simulation virtual reality, Z-width