PUMAH: Pan-tilt Ultrasound Mid-Air Haptics

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***Abstract*— Focused ultrasound mid-air haptic interfaces are ideal for providing tactile feedback in Virtual Reality (VR), as they do not require the user to be tethered to, hold, or wear any device. Using an array of ultrasound emitters, they generate focused points of oscillating high pressure in mid-air, eliciting vibrotactile sensations when encountering a user's skin. These arrays feature a large vertical workspace, but are not capable of displaying stimuli far beyond their horizontal limits, severely limiting their workspace in the lateral dimensions. This demo presents the PUMAH, a low-cost 2 degrees-of-freedom robotic system rotating a focused ultrasound array around the pan and tilt axes, enabling multi-directional tactile feedback and increasing the array's workspace volume more than 14-fold.**

I. Device and Demo Setup

The PUMAH [1] is a robotic system for increasing the usable workspace of focused ultrasound mid-air haptic interfaces (see Figure 1). In all presented interactions, the PUMAH's control law commands the device axis rotations so as to minimize angular error between the array normal vector and the vector between the pivot and user's palm.

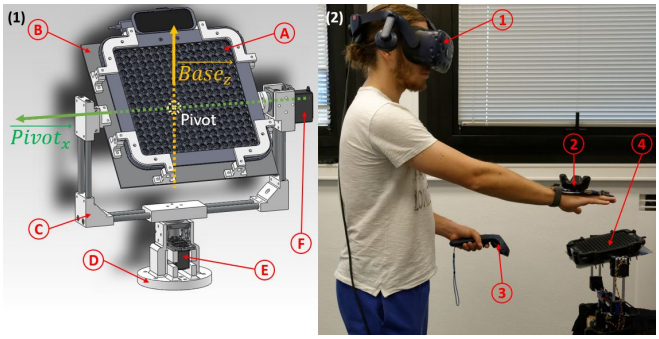

Fig. 1. (Left) The PUMAH: An ultrasound phased array (A) on a holder plate (B) rotates around the tilt axis $\overrightarrow{Pivot_x}$ (green) within a holder bracket (C). The bracket rotates around the pan axis $\overrightarrow{Base_z}$ (orange) relative to a static foot (D). HiTec HS625MG (E) and HS645MG (F) motors drive the pan and tilt axes. (Right) Demo VR setup: Users wear a HTC Vive headset (1) and a Vive tracker (2) tracks their dominant hand which receives tactile feedback from the PUMAH (4). They interact with demo menus using a Vive controller held in their non-dominant hand (3).

II. Interactions

Our demo contains four virtual scenes (see Fig. 2). All interactible objects are placed inside the PUMAH's workspace, and produce various tactile sensations when the user's hand avatar collides with them. All sensations are generated using Ultrahaptics' Unity Core Asset. To avoid collision between the PUMAH and the user's hand, solid virtual objects are placed in the PUMAH's location in most of the scenes. If the user's hand gets too close to the array, red bounding boxes are shown around the device position.

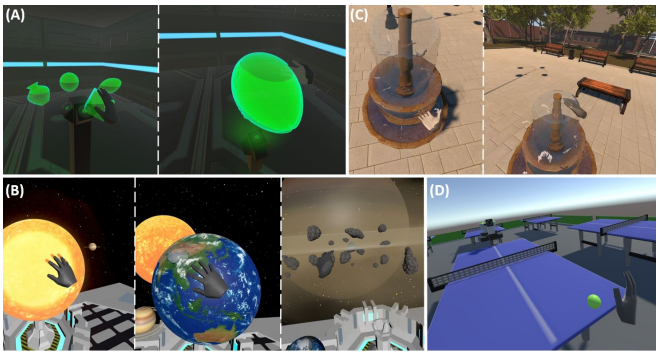

Fig. 2. The four virtual scenes in our demo: (A) Touchable holograms, (B) Virtual solar system, (C) Mid-air haptic fountain, (D) Haptic table-tennis.

a) Touchable holograms: A holographic projector displays a circular menu of 4 shapes around it (see Fig. 2-A). Users use a Vive controller to navigate through the menu of holograms. Fixed intensity vibrotactile feedback is provided when the user's hand collides with the virtual objects. To experience the increase in workspace provided by the PUMAH, the scene also features a button allowing switching between full use of the PUMAH's workspace and use of only the static array's workspace.

b) Virtual Solar System: Here, the user can interact with three celestial bodies within a model of the solar system (see Fig. 2-B). The sun is similar to the touchable holograms, but also emits solar flares which can be felt as sweeping vibrotactile sensations. For the earth, different sensations are produced when the ocean or land are touched. Finally, the rings of saturn produce various impact sensations.

c) Mid-air haptic fountain: A fountain is colocated with the PUMAH in the virtual scene, allowing the user's hand to interact with the flowing water from various angles (see Fig. 2-C). The tactile sensation is continuously updated to give an impression of water flow around the hand.

d) Haptic table-tennis: Here, the PUMAH provides haptic feedback for a game of VR ping-pong (see Fig. 2-D). Vibrotactile impacts are rendered with an intensity proportional to the ball's impact force on the hand.

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[1] are with CNRS, Univ Rennes, Inria, IRISA – Rennes, France. e-mail: {thomas.howard, guillaume.gicquel, claudio.pacchierotti}@irisa.fr

[3] is with Univ Rennes, Inria, CNRS, IRISA – Rennes, France. e-mail: anatole.lecuyer@inria.fr

[2] is with Univ Rennes, INSA, IRISA, Inria, CNRS – Rennes, France and Institut Universitaire de France. e-mail: maud.marchal@irisa.fr

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