Multipoint Rendering of Ultrasonic Haptic Points

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Abstract

Midair haptics enables free and natural haptic exploration without bothering attached devices and can be developed using a ultrasonic phased array. We introduce spatiotemporal scheduling schemes to render multiple ultrasonic haptic points in midair to overcome the lack of stimulus intensity and effective area in midair haptics. Our method is based on temporal switching of modulated ultrasonic signals and a competitive selection loop of haptic points in multiple ultrasonic modules. We could cover both hands with more than 50 haptic points simultaneously using the algorithm.

Methods

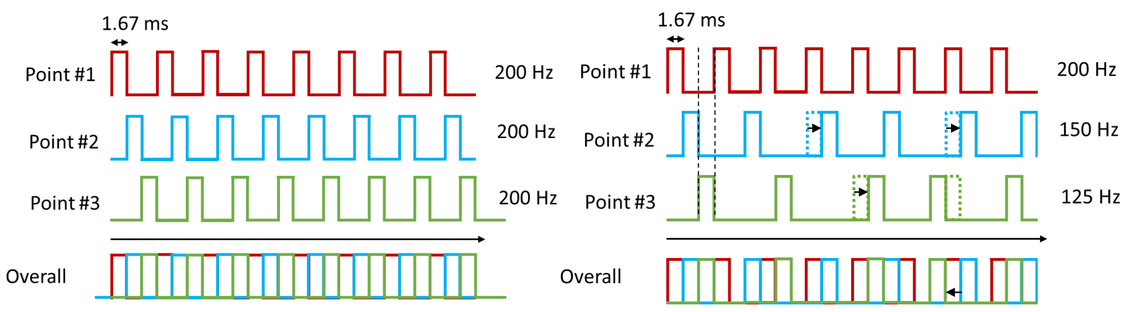
Simultaneous representation of multiple haptic points is essential to realize natural barehand interaction in midair. However, the intensity of a point is reduced drastically with the number of concurrent haptic points. We developed two techniques based on the characteristics of ultrasonic phased array and modulated signals to render more number of haptic points in a wider space at the same time.

Temporal Switching

First, we developed a temporal switching scheme that utilizes duty cycle of ultrasonic modulation. We drive each haptic point in a square (on/off) ultrasonic wave modulated at a vibration frequency (<1 kHz). In the previous method, the ultrasonic array turned on and becomes idle during the off state to render a haptic point. They needed to divide the power or drive each point sequentially to handle multiple points.

We shifted the phase of each point to establish an alternating operation to reduce the idle time. In our algorithm, the period of on state is reduced by the number of haptic points and the on state of each haptic point is not overlapped each other to maximize the intensity.

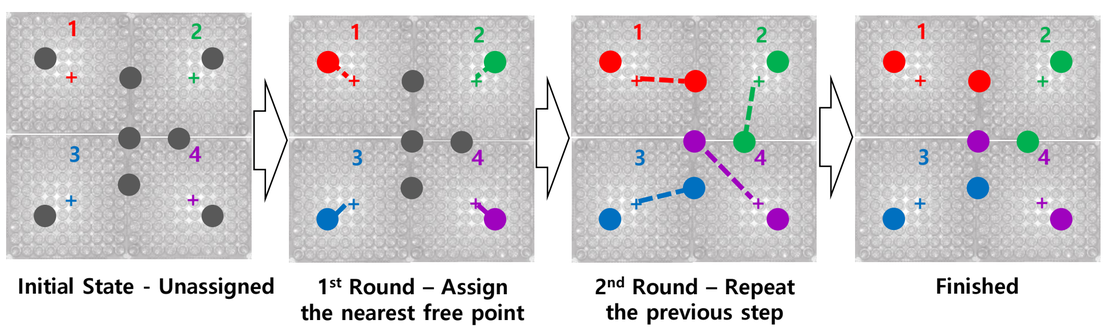
When the haptic points have different vibration frequencies, we can remove the overlap by temporary shifts of pulses. The shift is determined to minimize the skew of frequency below the discrimination threshold (~15%).



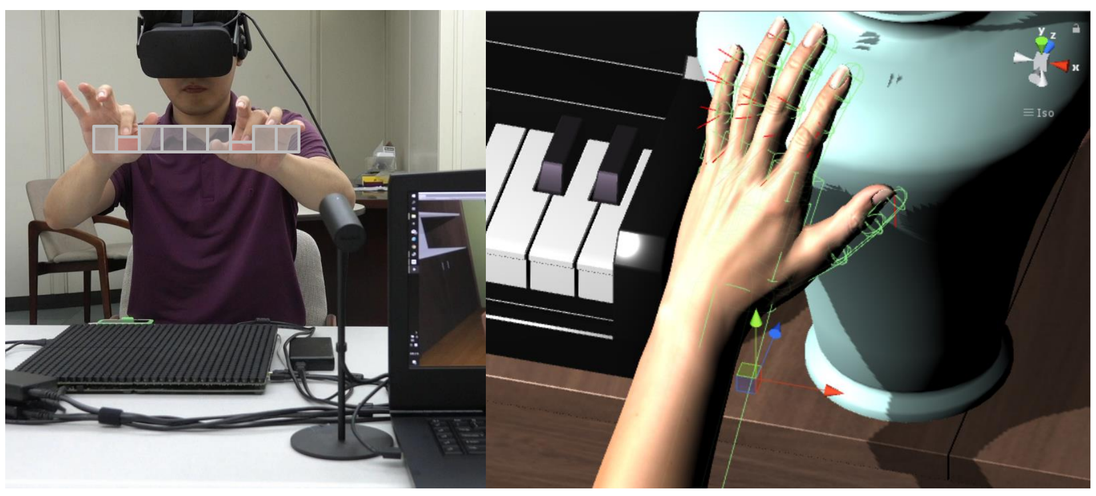
Spatial Scheduling

We tried to increase the workspace of midair haptic display by integrating multiple transducer arrays together. Our approach is based on individual operation of array modules rather than a unified control of all transducers in arrays. The individual operation can reduce the computation complexity than that of the unified control method and easy to achieve the realtime performance.

Our scheme is based on a simple player draft system for haptic points in a scene. In this algorithm, each transducer array module selects a haptic point with minimal rendering cost in every ‘round’. The rounds continue until there is a remained point. A cost value for every point-array pair is calculated on every update of haptic points. We used the distance between the haptic point and position for maximum output as the cost value. The form and parameters of the cost function can be modified including modulation frequency, point priority, and so on. We can change the layout of transducer modules freely with the spatial scheduling.



Results



We implemented our algorithm on our midair piano playing system: AirPiano. We could handle more than 50 haptic points to cover both hands using 1K ultrasound transducers. The user could touch virtual objects freely using their palms and fingers. Our spatial scheduling is not optimal yet and the feedback is weak compared to the real keypress feeling. However, we hope that this study can show a way to improve midair haptic experience.

ASLLA Symposium

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