SICE Annual Conference 2013
September 14-17, 2013, Nagoya University, Nagoya, Japan

Compact Device for Markerless Hand Tracking and Noncontact Tactile Feedback

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Abstract: A compact device is introduced which enables users not only to operate computers by moving their hands in mid-air but also to feel haptic feedback on their hands. The device consists of a depth camera for hand tracking and a noncontact tactile display for haptic feedback. The tactile display utilizes focused ultrasound to produce tactile stimulation from a distance. The principles are described and the developed device is described.

Keywords: Natural user interface, depth camera, tactile display, airborne ultrasound, acoustic radiation pressure.

1. INTRODUCTION

Natural User Interfaces (NUI) are getting popular these years. It is mainly due to the spread of depth cameras such as Kinect [1]. Users are free from wearing devices thanks to depth cameras unlike conventional positioning technologies (for example, patterned markers in ARToolKit [2], retro-reflective markers or IR LEDs in IR-based methods [3], sensor units in magnetic methods [4], and so on).

Adding haptic feedback to NUI is the next step and related researches have been reported. Wearable haptic devices are controlled based on the data from a depth camera in [5]. Other researches with different positioning technologies also use wearable devices for haptic feedback [6][7]. If haptic feedback is device-less as well as position sensing, users are able to use NUI and feel haptic feedback with their bare hands. Then, for example, users can use the system with their hands being wet or dirty. They feel free to use it for a short time. They can use it simultaneously or alternately.

The author developed a system consisting of a depth camera and a noncontact tactile display [8] (Fig. 1) for that purpose mentioned above. The depth camera used in this system is Kinect. The tactile display is Airborne Ultrasound Tactile Display (AUTD) [9] which utilizes focused ultrasound to stimulate users' hands tactually in midair. There are two inconvenience points in this system. One is that the depth camera and the tactile display have to be placed separately because the minimum sensing range of Kinect (50 cm) is longer than the maximum stimulating range of AUTD (around 40 cm). The other is that the ultrasound transducer arrays of AUTD are connected to the driving circuits by hundreds of long wires. These lead to the lack of mobility of the system.

A newly developed device (Fig. 2) is introduced in this paper. It is a combination of a depth camera whose minimum sensing range is 15 cm (DepthSense 325 [10]) and the latest version of AUTD [11] which is integrated to be small and compact. The depth camera is attached on the tactile display. The rest of this paper describes the two technologies and the developed compact device.

2. TECHNOLOGIES

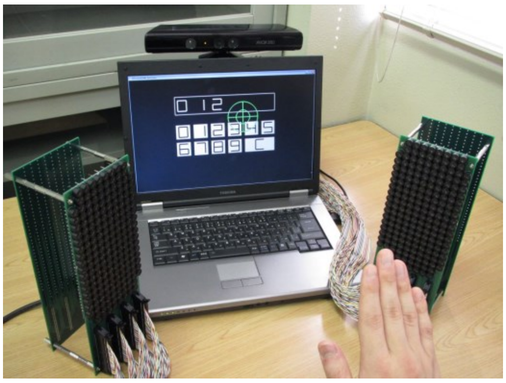

Fig. 1 Previous system [8].

Fig. 2 New device for NUI with tactile feedback.

2.1 Depth camera

The specifications of DepthSense 325 [10] are as follows. It obtains a depth map based on Time-of-Flight of IR light. The sensing range is from 15 cm to 100 cm. The depth resolution is less than 1.4 cm. The angle of view is 74 deg × 58 deg (H×V). The pixel count is 320×240. The size is 10.5×3.0×2.3 cm^3. It communicates with a PC and is also powered via USB.

2.2 Tactile display

The noncontact tactile display is based on a nonlinear phenomenon of ultrasound: Acoustic radiation pressure [9]. When the ultrasound beam is reflected vertically at an object surface, the surface is subjected to the constant vertical force in the direction of the incident beam. Assuming a plane wave, the acoustic radiation pressure P [Pa] is described as

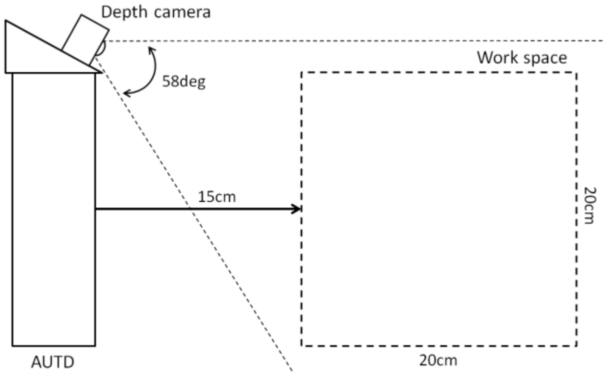

Fig. 2 Side view of developed device and work space.

$$P = \alpha \frac{p^2}{\rho c^2} \quad (1)$$

where c [m/s] is the sound speed, p [Pa] is the RMS sound pressure of ultrasound, and ρ [kg/m^3] is the density of medium. α is the constant depending on the amplitude reflection coefficient at an object surface and it is nearly equal to 2 in the case of the human skin. Equation (1) suggests that the spatial distribution of the radiation pressure P can be controlled by synthesizing the spatial distribution of the ultrasound p.

The Phased Array Focusing technique is used to produce the radiation pressure perceivable by human skins [9]. The focal point of ultrasound is generated by setting adequate phase delays of multiple transducers. The focal point can be moved to an arbitrary position by controlling the phase delays. It is theoretically derived that the spatial distribution of ultrasound generated from a rectangular transducer array is nearly sinc-function shaped. The width of the main lobe (w [m]) parallel to the side of the rectangular is written as

$$w = \frac{2\lambda R}{D} \quad (2)$$

where λ [m] is the wavelength, R [m] is the focal length, and D [m] is the side length of the rectangular array. Equation (2) indicates that the spatial resolution and the array size are in the relationship of trade-off.

The specifications of the latest version of AUTD [11] are as follows. It is designed to be all-in-one and communicates with a PC via USB interface. The size is $19\times19\times5$ cm^3. The weight is 0.6 kg. The maximum output force is 16 mN. The size of the focal point w is 20 mm when the focal length R is set at 20 cm. The spatial resolution of the position of the focal point is 0.5 mm. The position can be updated at the rate of 1 kHz.

3. COMPACT DEVICE FOR NUI WITH TACTILE FEEDBACK

The depth camera is attached on the noncontact tactile display to realize a movable NUI system with haptic feedback (Fig. 2). The angle of view of the depth camera is taken into account to cover 20×20 cm^2 area at the range from 15 cm to 35 cm. 29 deg is selected as an inclination angle between the depth camera and the tactile display (Fig. 3). This device is aimed to be used on a desk rather than on a wall because the work space is relatively small and near to the tactile display.

The size of the focal point of the latest version of AUTD is sharper than that of the previous one [8] (for example, at a distance of 20 cm, 20×20 mm^2 and 17×34 mm^2, respectively). The latest one thus can target a single finger or reproduce various spatio-temporal patterns on a palm (for example, symbols, letters, and even hand-drawn trajectories) while the previous one targets multi fingers and only provides tactile cues because its focal point is wide.

4. CONCLUSION

A compact device for NUI with haptic feedback was presented in this paper. A depth camera is used for markerless hand tracking and an ultrasound-based tactile display is used for noncontact haptic feedback. The combination of these two technologies enables users to operate computers feeling not only visual and audio feedback but also haptic feedback directly on their bare hands.

The device has just developed as of now and software such as hand tracking is to be implemented. Future works also include
(1) evaluating the performance of the developed device,
(2) exploring applications of the device, and
(3) optimizing the device according to the requirements of each application (device size, output force, etc.).

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(All URLs were last accessed on 21 June 2013.)