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ABSTRACT

Air is one of medium that has several properties that has a lot of potential to be used for developing various novel interaction devices for Human Computer Interactions (HCI). It has a wide range of use and application that is not limited for standard interfaces but also specialized interfaces such as for game interfaces and medical interfaces.

Although there have been several research on utilizing air for developing interaction devices. *There are no research that utilize air to provide multiple interaction in one integrated interface*. Therefore we are particularly interested in **developing novel devices** that capable to **provide multiple interaction options** in a single integrated interface, e.g., can work both as input interface as well as output interfaces.

We designed and developed several novel air-based prototypes using two air properties which are air-flow and air-pressure. In general, our work is categorized into three applications that can best leverage the use of air properties and show the significant impact of air-based device for human computer interaction – (i) multimodal interactions (visual and tactile), (ii) fMRI-compatible interfaces (input and tactile), and (iii) game interfaces (input and tactile)

In this dissertation, first, we explored the use of air-flow capability to manipulate small objects by levitation. We designed and developed two air-flow-based prototypes – (i) an air-based multimodal tactile display (Study 1) and (ii) a novel fMRI-compatible input devices using air-flow (Study 3). To evaluate the prototypes, we conducted user studies for understanding user performance and perception on air tactile devices (Study 2).

Second, we explored the use of air-pressure capability for air-based interaction devices. We designed and developed several prototypes for applications – (i)

fMRI-compatible interaction devices (Study 4) and (ii) game interaction devices (Study 5). See Figure 1 for the dissertation outline.

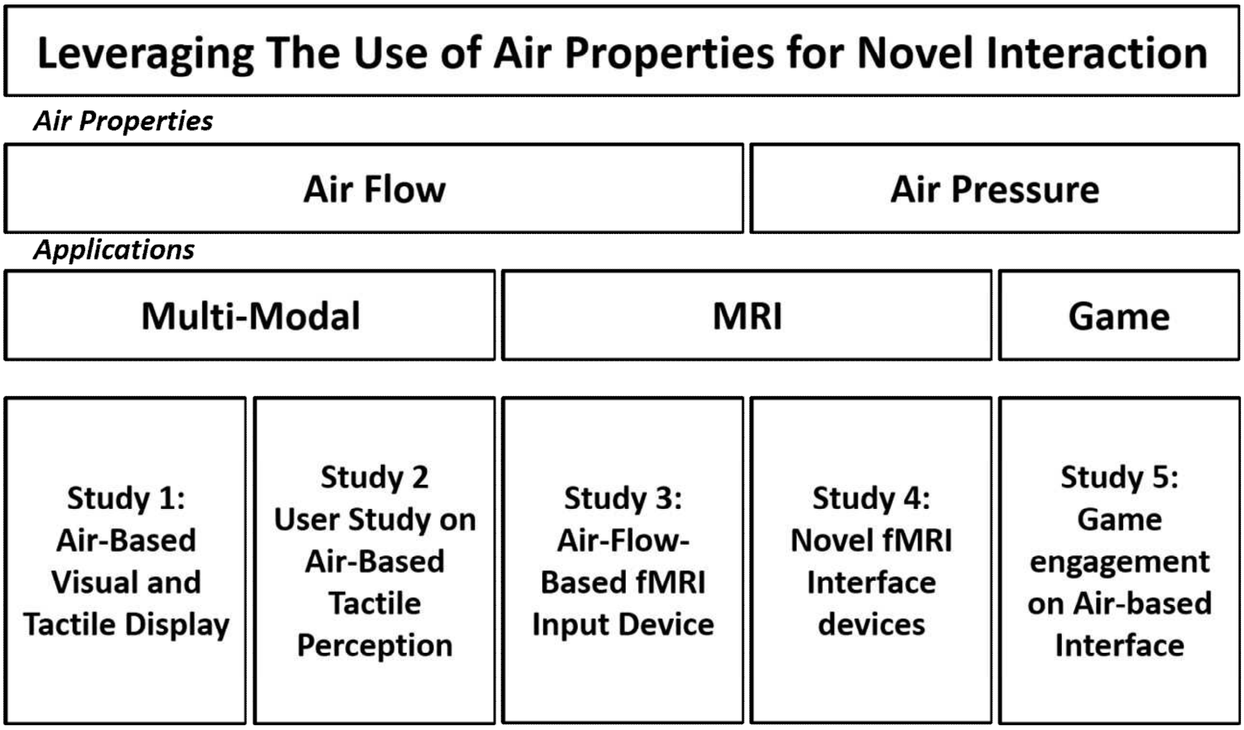

Figure 1. Outline of Dissertation

Summary of findings:

1. We developed a working prototype that is capable to provide physical visualization using arrays of levitated balls and provide non-contact tactile feedback, by utilizing air flow property. [Study 1]
2. We proved that adding physical visual feedback using levitated balls can significantly improve user's subjective tactile perceptions. [Study 2]
3. We proposed an input interface design using air-flow property that allows two interactions (tap and slide) with a single device to be used inside MRI environment. [Study 3]
4. We proved that air-based interfaces is compatible and can be used safely in high magnetic field environment. [Study 4]

5. We identified that air-pressure can be utilized to provide both input and output interfaces within a single integrated system. [Study 4]
6. We identified that user preference in game input device can significantly improve user's immersion level while playing a specific game using air-based devices. [Study5]

Study 1: Air-Based Visual and Tactile Display

Representing data using physical objects has been done for as long as human started to count, e.g., using stones/twigs for counting, or stacking stones to represent simple graph. Although computer graphics (CG) have higher resolution and are able to show animated representation of information, direct visual perception allows a richer experience by stimulating the user's visual senses Touch sensation is reported to increase the user's experience in interactions because it engages more bodily senses.

The main challenge for visualizing data using physical objects is represent changes in data dynamically. Touching a levitated object directly can disturb and occlude visual perception of the physical visualization. Thus there is a need for tactile awareness without directly touching and disturbing the feedback with the user's hand.

Some previous works provided non-contact tactile sensation by using air and ultrasound. However, these devices are dedicated to generate non-contact tactile sensations only and they do not support this with direct visual feedback (i.e., physical visualization).

Therefore, we explored the suitability of air-properties to concurrently generate non-contact tactile sensations with dynamic physical visualization. Additionally, we explored the ability of air flow force to create the sensation of patterns. The distinguishing feature of our prototype is that it can generate multi-point tactile stimuli and augment it with additional direct visual perception (i.e., physical visualization).

Finding: The transparent body/tube of the prototype is important not only as the container for the levitated ball, but also to enhance the air flow force. As for the air flow force with nozzle, the nozzle with a 1 cm height and 10 degree angle has the best overall air flow force for distances from 3 to 15 cm. Although air flow force with nozzle is slightly lower for short distances compared to the non-nozzle condition, air-tactile sensations with nozzle are better compared to the non-nozzle condition.

Study 2: User Study on Air-Based Tactile Perception

To understand the effect of different visual feedback condition to user perception of non-contact tactile feedback, we conducted a systematic user study. The study also considers haptic perception on different haptic feedback patterns and various hand positions i.e., the significance of distance from the top of the device.

We studied users perceived air-tactile perception in association with three different visual conditions, (i) tactile only without visual feedback, (ii) tactile feedback with visual feedback using computer graphic image on a monitor, and (iii) tactile feedback with direct visual perception using physical visual feedback (our prototype).

Twelve participants from 5 difference nationalities were recruited, eight males, aged 21 to 28 (M = 24.4, SD = 2.4).

Findings: Non-contact air-tactile stimulus of our prototype is sufficient to provide a significantly high detection rate by all participants in determining the position and/or the pattern generated. Moreover, the study results indicate that the direct visual perception of our prototype enhances the user's tactile perception level compared to visual representation on a monitor.

Study 3: Air-Flow Based fMRI Input Device

The strong magnetic field of functional magnetic resonance imaging (fMRI) and the supine position (lying with the face up) of participants in fMRI scanners severely limit how participants can interact during fMRI experiments.

Air flow explored to design and develop the interaction system that allows participant interact with experimenter during and fMRI experiments.

The air-flow-based system is designed to allow simple interactions with simultaneous soft air-tactile feedback to users. In this work, we used the air-flow-based system to allow users to have a soft air-flow sensation and a simple precise control over a levitated ball inside a transparent tube at the same time.

The air-flow-based system consists of a fan-motor, a ball (diameter 8 mm) in a transparent tube (inner diameter of 1 cm, thickness 3 mm), an 8-meter long transparent tube (inner diameter of 1 cm, thickness 3 mm), a flow meter (range 100 mL/min to 1500 mL/min), an Arduino microcontroller and a 3D printed interaction device. The Arduino controller turns on the fan-motor generating air-flow through the transparent tube to 3D the printed hand-nozzle device which is held by the user. The hand-nozzle device was developed using a uPrint SE 3D printer with ivory color ABSplus material.

Findings: Despite its simple setup, this system allows both soft tactile feedback (with just-noticeable differences (JND) in air flow pressure) while concurrently recording user behavior when precisely controlling the ball position, which normally could not be achieved with an optical-fiber-based system.

Study 4: Novel fMRI Interface Devices

Air-based (pneumatic) devices are invulnerable to EMI and lack of EMS. Pneumatic-based devices have also been used in various fMRI applications such as robot interaction, skin stimulation, haptic interfaces.

However, these devices are limited to one configuration and only provide stimulation to participants without sensing and/or recording participants' response information.

Thus we proposes a complimentary method for designing and developing fMRI-compatible devices that are able to both record participant responses and provide stimulation (such as soft tactile feedback and fragrance signal) to the participants in fMRI environment.

We explored the use of air-pressure properties, or designing and developing various interaction devices for use in the fMRI. We also explored the use of 3D printer, plastic pockets, and off-the-shelf materials to enable fast development and replication of various custom interaction devices for use in fMRI environment.

Although manual construction such as plastic welding is considered cumbersome and error prone compared to 3D printing, it is one of the fastest methods in fabricating air-pocket for using with pneumatic systems. We explored a combination of plastic welding and 3D printing to develop various pneumatic chambers (air-pockets) to be used in our interaction devices. Fabricating using plastic welding allow fast development which are used to provide proof-of-concept of the developed design then refined using 3D printing.

To evaluate our proposed prototypes, we conducted informal interviews with several expert fMRI researchers who have been using fMRI for experiment for more than 5 years to find out what possible interaction device functions may be required, which are currently unavailable and which may be made possible by using the proposed air based interaction devices. We also conducted an evaluation experiment for fMRI-compatibility of the developed devices on a 3.0 Tesla fMRI scanner. The evaluation results show that air-based interaction devices are effective and that they comply with standards for device in fMRI

Findings: Our developed air-based prototypes comply with safety standard of fMRI-compatible devices. We also confirm that the prototypes can be used for continuous input device and also for giving soft tactile sensation concurrently. We also have provided several design consideration to develop air-based interaction device for use in fMRI environment. Furthermore, we proposed some applications of the prototypes.

Study 5: Game Engagement on Air-Based Interface

Playing computer games is an enjoyable activity that is loved by many people. One integral game component that contributes to great player experiences is game input devices. Keyboard and gamepad are two most commonly used input devices in video games.

However, the traditional input paradigm only supports binary and directional input and thus, interaction bandwidth can be limited. This paper explores a novel parameter, i.e., *air pressure*, for game input. Air pressure supports continuous value, as opposed to binary input in keyboard or gamepad. This continuous value is particularly intuitive in games where there is a range of possible values, e.g., hitting a drum with different forces produces different sound. To explore the feasibility, we developed a device prototype that supports air pressure input.

This study compared engagement and usability between a keyboard, a gamepad and air-based device. The engagement was measured using the IEQ, a 31 item questionnaire with five-point Likert scale items. This questionnaire can provide an overall measure of immersion as well as five factor of immersion, which are cognitive involvement, emotional involvement, real world dissociation, challenge, and control. We hypothesized that playing the game using air-based device can achieve higher immersion rating compared to playing using keyboard or gamepad.

We also explored the usefulness of our prototype for game interaction in two custom-made games (flappy bird-like game and simple rhythm game). As for the selection of game genres, since both games are based on repetitive target-acquisition task, it serves as a good game for hand grip interaction which require repetitive griping.

Findings: Our comparison with keyboard and gamepad found that air-based device outperformed other devices in immersion and fun, was well-accepted by participants, and can achieve equal performance after five trials of training. This suggests that air pressure can serve as a promising input for game interaction and can provide new forms of play.