# Crossing-in-Air: A New Crossing-based Technique for Intangible User Interfaces

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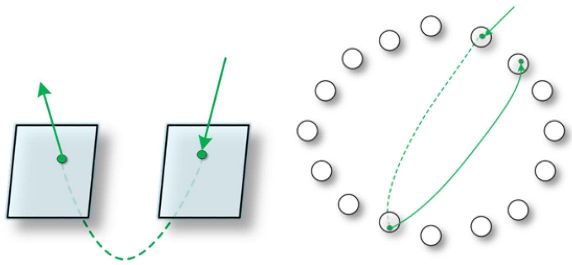
## 1 Introduction

Intangible user interface is a user interface in which a person interacts with digital information but not through any physical environment. Although the notion of intangible user interface has been around for decades, it didn't widespread because of the limited interaction paradigm and its' awkward feeling of "touching" a mid-air display[1]. In this work, we extend the design space of intangible interaction by proposing the concept of "Crossing-in-Air": after a standard direct touch input, since user's hand is potentially behind the virtual object, we take advantage of the fact that user's hand has to go back to propose an additional input.

## 2 Experiment One: Crossing Interaction's Performance

In the first experiment, we did a fundamental evaluation about direct-touch and the crossing technique's performance in one and two dimensions. Crossing interaction in two dimensions' schematic diagram are depicted in Figure 1.



(a) One-Dimension (b) Two-Dimensions

Figure 1 The Crossing Technique in One and Two Dimensions

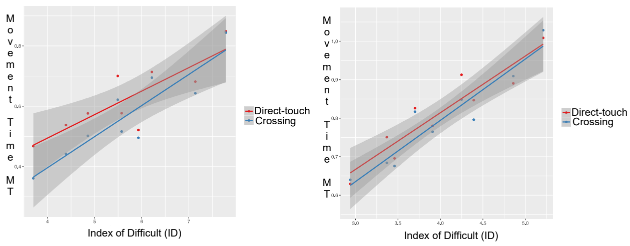
The first experiment is a standard Fitts' Law one and two dimension experiment with three different angles. The experiment design is within-subjects, repeated measures. Task order was counterbalanced using a Latin Square. Seven male and five female volunteers, 21-34 years old (average 25 years old), participated in the experiment. A post-experiment questionnaire collected subjective participant opinion of crossing and direct-touch interaction.

Fitts' Law, a quantitive human performance model, has provided a scientific foundation for evaluating and designing pointing-based user interfaces. The relationship between movement time ($MT$) and the index of difficulty ($ID$) described in Eq.(1) is a widely used form to model Fitts' law, and $a$ and $b$ are constants reflecting the efficiency of the pointing system.

$$MT = a + bID \quad (1)$$

The index of difficulty's calculation formula showed in Eq.(2), where $A$ means the distance between the centers of the start target and the end target, $W$ represents the width of the end target in the direction of travel. And $ID$ is measured in bits.

$$ID = \log_2(A/W + 1) \quad (2)$$

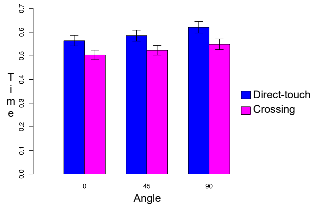



(a) One-Dimension (b) Two-Dimensions

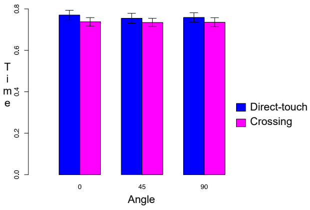
Figure 2 Fitts' Law Regression in One and Two Dimensions

As we can see in Figure 2, Fitts' Law's regression result. The crossing technique follows a similar regression line to direct-touch interaction, suggesting a possibility of substituting the pointing task with the crossing task. And crossing interaction is faster than direct-touch for most IDs. The regression line of crossing intersects that of direct-touch at a high ID, indicating crossing can be an alternative to direct-touch for selecting big and near targets.

Two techniques performance comparison in Figure 3. shows, firstly angle didn't effect participant's performance too much ($p=0.78$). In one dimension, crossing interaction is faster than direct-touch ($p=0.03$, effect size=0.45). But in two dimension, crossing is not significantly faster than direct-touch ($p=0.558$). In post-experiment questionnaire, most of participants prefer RTV rather than direct-touch.




(a) One-Dimension




(b) Two-Dimensions

Figure 3 Speed Comparison in One and Two Dimensions

## 3 Experiment Two: Crossing-Keyboard

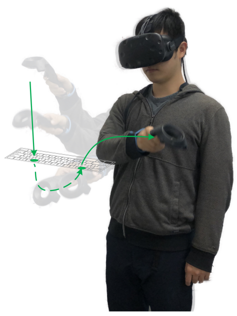


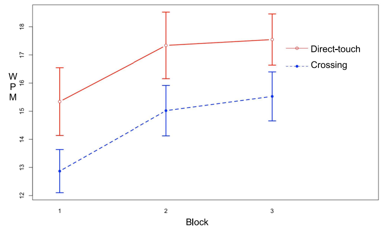
Figure 4 Crossing-keyboard

VR (Virtual Reality) as a common intangible display system, VR devices have become more widespread. Since user can not use physical keyboard with HMD (Head-Mounted Display), VR's text entry problem is still challenging. As one of our concept applications, We applied our "Crossing-in-Air" concept into VR's virtual keyboard, we call it "Crossing-Keyboard" (Figure 5). In order to know our keyboard's learnability, input speed performance and accuracy, we designed and performed a three sessions' comparative experiment between our keyboard and VR's direct-touch keyboard.

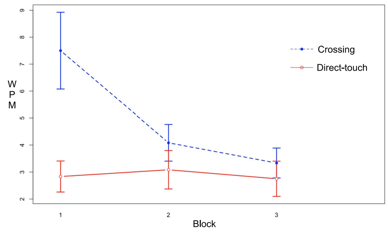

Figure 5 Keyboard Screenshot

A total of 12 participants (6 males, 6 females) volunteered in this experiment. The virtual environment consisted of a virtual representation of a standard QWERTY keyboard (Figure 5) in the participants ' interaction zone in a comfortable distance for mid-air interaction, and a text area for the output at eye sight.

WPM (Words Per Minute) is a calculation of how fast people type with no error penalties. The gross typing speed is calculated by taking all words typed and dividing by the time it took to type the words in minutes. As shown in Figure 6a, crossing interaction's WPM is less than direct-touch's (p=0.005). But participants report that "Crossing-Keyboard" do not have any awkward feeling of "touching air" because of its flow-like gesture.




(a) WPM




(b) Error Rate

Figure 6 VR keyboard's Input Speed and Error Rate

Error rate is defined as the percentage of error entries out of the total entries typed. In Figure 6b, crossing interaction's error rate is higher than direct-touch's at the very beginning, but along with participants's practice, crossing's error rate drops quickly. And at the third block, crossing's error rate is no more than direct-touch's.

## 4 Conclusion

We designed experiment to validate the "Crossing-in-Air" interaction still follows Fitts' Law, and it can outperform the direct touch significantly in one dimension. We discuss and propose several design prototypes with "Crossing-in-Air" concept, and had a quantitative experiment with the Crossing-keyboard, one of the prototypes. After two quantitative experiments and post-experiment subjective questionnaire, we can conclute that in some situations, Crossing-in-Air interaction outperform the normal direct-touch interaction, but it also have its own drawbacks. Participants report a positive impression in subjective questionnaire.

## References

[1] Chan, Li-Wei, et al. "Touching the void: direct-touch interaction for intangible displays." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2010.