TiTAN: Exploring Midair Text Entry using Freehand Input

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Abstract

TiTAN is a spatial user interface that enables freehand, midair text entry with a distant display while only requiring a low-cost depth sensor. Our system aims to leverage one's familiarity with the QWERTY layout. It allows users to input text, in midair, by mimicking the typing action they typically perform on a physical keyboard or touchscreen. Here, both hands and ten fingers are individually tracked, along with click action detection which enables a wide variety of interactions. We propose three midair text entry techniques and evaluate the TiTAN system with two different sensors.

Author Keywords

Text entry; midair interaction; typing in thin air; gesture;

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation (e.g. HCI)]: User interfaces—*Input devices and strategies*;

Introduction

Midair interaction [1, 5, 7, 12, 14, 17, 18, 20, 22] is an emerging input modality for HCI, in particular for scenarios involving public displays [11, 18], large surface [15], augmented and virtual reality [1] and sterile conditions (e.g., surgery). However, midair text entry has not received as much attention with most solutions requiring either the use of an external controller [1, 6, 14] or reflective markers [12]. Text entry,

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CHI'17 Extended Abstracts, May 06-11, 2017, Denver, CO, USA.
ACM 978-1-4503-4656-6/17/05.
http://dx.doi.org/10.1145/3027063.3053228

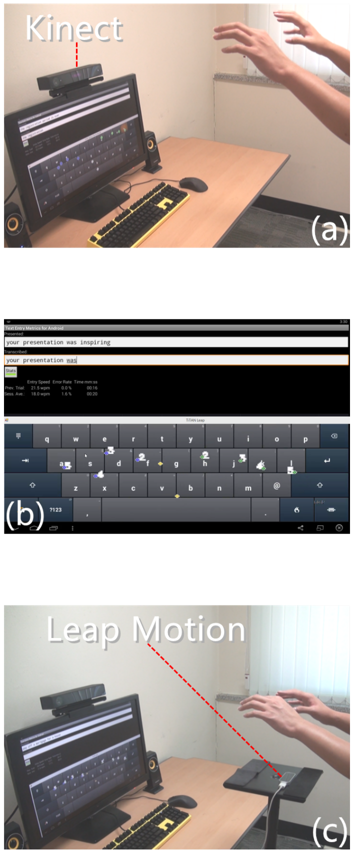

Figure 1: (a) System setup using Kinect (b) System screen-shot (c) System setup using Leap Motion.

in midair, can be useful in many walk-up-and-use scenarios where an external device or touch screen is not available. Hence, effective text entry should not be limited to the availability of mechanical devices or fixed touch surfaces alone.

This paper proposes and prototypes a novel approach to midair text entry interaction which leverages the dexterity of human hands and fingers. Taking text entry beyond existing mechanical devices or fixed touch surfaces, our system offers extended mobility with an on-demand text entry solution. Here we present *TiTAN: Typing in Thin Air Naturally*, a virtual keyboard system that enables midair text entry on a distant display, requiring only a low-cost depth sensor. It supports "walk-up-and-use" and on-demand interactive capabilities, with no calibration required. Our goal is to support users simply raising their hands to start typing in midair. Each finger tapping action inputs a different character based on the common QWERTY layout. This leverages potential skill transfer, from the physical keyboard, for everyday computer users. We also describe two formative studies comparing the performance of the three proposed techniques i) hunt-and-peck ii) touch typing and iii) shape writing, using a Kinect v2 [13] and a Leap Motion [9].

Related Work

Earlier midair text entry techniques have taken two primary forms: i) selection or ii) gesture based. Each technique is further differentiated by the device it uses, be it controller-based, marker-based or freehand input. Yet, existing approaches for midair text entry often suffer from inherent constraints, such as requiring a user to hold an external device (Wiimote) [6] or even wearing multiple reflective markers that are tracked by expensive infrastructure [12]. Whereas other device-free approaches [5, 7] only allow single character entry at a time, and only utilize one hand, which can be ineffective or may cause strain on that hand.

Selection-based Techniques

Using a Wiimote controller with ray-casting technique over projected keyboard, Shoemaker et al. [18] were able to achieve 18.9 WPM with their best layout. It is worth noting that, unlike recent unconstrained text entry evaluation [24], their system does not allow further inputs upon error occurrence, with the addition of tactile feedback. Using IR reflective markers tracked by multiple infrared cameras (Vicon/Optitrack), Markussen et al. [11] were able to achieve 9.5 WPM on the first session and 13.2 WPM by the sixth session. Taking a more affordable approach, Ren et al. [16] prototype a midair typing solution using a Microsoft Kinect and were able to achieve 6.11 WPM by the first day and 8.57 WPM on the fifth day. Their method uses either dwell or push forward as a delimiter, which is slow and tiring in addition to suffering from hand tremor and hand drift. Similarly, Hincapié-Ramos et al. [5] discuss the problem of consumed endurance of midair interaction and demonstrated a free-hand text entry speed of 4.55 WPM, using a dwell technique with only one hand.

Gesture-based Techniques

GesText [6] employs a Wiimote controller to translate detected hand motions into text input. It reports a walk-up-and-use speed of 3.7 WPM and then 5.3 WPM after training over four days. TiltText [23] combines tilt with a keypad on the mobile phone to disambiguate the input of each letter on the same key and reported a novice speed of 7.42 WPM and last block speed of 13.57 WPM. Ni et al. [14] created AirStroke, a Graffiti based approach that uses a pinch glove and a color marker. It shows novice speed of 3 to 6 WPM (without/with word completion) while progressing to 9 to 13 WPM (without/with word completion) by the 20th session. Kristensson et al. [7] demonstrated free-hand Graffiti using single hand with good accuracy, but no results on speed were provided. All these gesture-based approaches require the user to learn new layouts or gestures and may impose a steep learning curve. Recently, Vulture [12] adopted shape writing [8] as a midair text entry solution. It reports 11.8 WPM and 20.6 WPM on the first and the tenth session. Similarly, SWiM [26] incorporated shape writing with tilting a large phone and achieved 15 to 32 WPM. Shape writing is easy to learn and exhibits advantages when writing English words but not with abbreviation, email addresses or passwords. Sridhar et al. [20] explore chording in midair using a Leap Motion but only measured the peak performance. Unfortunately, chording is not commonly understood and requires more learning. Finally, ATK [27] is the state-of-the-art system that tracks each finger to input text and achieves 23-29 WPM. It is similar work to us, except ATK is limited to very short range only (roughly 30 cm) and relies heavily on word-level correction. In contrast, our system supports front-facing interaction from a distance between 1-2 meters.

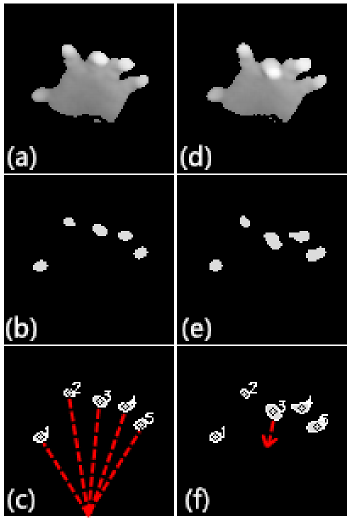

Figure 2: (a-c) Fingertip detection (d-f) Tap detection.

Design and Implementation

In this section, we outline the design of the virtual keyboard for midair text entry and describe how the interaction works. Our goal is to allow freehand input without requiring us to instrument the users with any controller or markers. Given that interactions with the midair system are usually short-lived, it is essential to support walk-up-and-use with minimal training while achieving acceptable text entry rate at the same time. Whereas physical a keyboard offers three input states (hovering, resting and depressing a key), midair keyboard offers only the first and third state (no resting). There is also no separate signal for pressure and touch feedback, making midair typing a significant challenge. With this in mind, we propose three techniques for midair text entry:

Bi-manual Hunt-and-Peck Typing Extending on previous works on selection-based text entry [5, 11, 16, 17, 18], our technique supports bi-manual entry utilizing both hands while without requiring holding controller or marker. The user controls two on-screen pointers that hover on a virtual keyboard. The user can perform a finger tapping action to select a character, akin to the two fingers hunt-and-peck typing on a physical keyboard or a touch surface.

Ten Finger Touch Typing We propose a novel ten finger midair typing approach that attempts to mimic the touch-typing action of average computer users on a physical keyboard. The user controls ten on-screen pointers that hover on a virtual keyboard with QWERTY layout, where each pointer corresponds to each finger. The user can tap any finger to insert a character based on the pointer's current position. In addition, right thumb and left thumb are reserved for inserting a space or backspace, which minimize the time required for homing for the keys that are far away.

One Hand Shape Writing Similar to Vulture [12], we adapted shape writing [8] technique to midair with using finger pinch as the delimiter. The difference is we are exploring and investigating how midair shape writing compares to other techniques using only a low-cost commodity depth sensor.

Implementation

We developed a proof-of-concept prototype, shown in figure 1 and supplementary video, using low-cost sensors such as Kinect v2 and Leap Motion. Kinect supports longer range but has no finger tracking capabilities while Leap Motion supports robust finger tracking, albeit at much shorter range. Our system is able to track the 3D position of hands and individual fingers, whether they are clicked or hovering.

Palm and Finger Recognition

We used a hybrid approach by leveraging on the robust body skeleton tracking [19] of Kinect SDK, where we define a region of interest (ROI) around the palm joint of each hand and extract the depth map (figure 2a), then process

Figure 3: Different static gestures can be recognized, top to bottom: L, lasso, O, OK, rotation.

them independently. In order to extract the fingertips that are pointing towards the camera, we use depth thresholding starting from the palm center and extract the remaining blobs (figure 2b). The blobs are eroded and smoothed with Gaussian blur. Then, we find the moments and calculate the center of gravity of each extracted blob (figure 2c). As we know the handedness tracked by Kinect, we can recognize each finger based on its orientation (figure 2c) by sorting the fingertip of the left hand in a counter-clockwise order, relative to a reference point at the bottom of the ROI (clockwise order for the right hand). Finally, all fingertip positions are smoothed using Kalman filter to reduce jitter. For Leap Motion [9], rather robust finger tracking is already provided in the SDK, similar to the one used in ATK [27].

Midair Finger Tapping Detection

The finger recognition step above yields the spatial position (X, Y, Z) of the ten fingers. We then classify each finger that accelerates fast towards the center of palm as a finger tap, much like a typing action (figure 2f). To reduce false positives when the hand is moving or shaking, we compute the distance traveled for all five fingers within a time window and reject any click if the palm movement is high. We also adapted this rejection technique to Leap Motion. To compensate for the lack of tactile feedback, each keystroke is accompanied by an audible “click” sound. We further reject a burst of clicks to prevent accidental input as a result of flickering between click states in quick succession.

Static Gesture for Text Manipulation

In a virtual keyboard system, it is important to support text manipulation. Our system allows text manipulation (selection, copy, paste, etc.) without requiring the user to home in for a mouse, by mapping different static hand gestures into different keyboard commands. Various static gestures are recognized based on a heuristic approach [25] (figure 3).

Evaluation

By evaluating the three proposed techniques with contrasting points in a design space, this study aims to provide a better understanding of midair text entry. Due to the small pool of participants and relatively short study, we focus on the immediate usability for walk-up-and-use scenarios.

Participants and Apparatus

We recruited 6 paid students (male), ages ranged from 22-28 (M=24). They have no previous experience on midair text entry nor shape writing technique. Their written English skills were between 3 and 4 (M=3.5) on a 7-point scale. The study was conducted on a 27 inch display. The participants stood 1.2 meters away from the Kinect. The virtual keyboard is roughly 53 cm x 15 cm in dimension. We used TEMA [3] to administer our study, which present random phrases and log the transcribed text. We analyzed the log file using StreamAnalyzer [24]. We emulated an Android system in a Windows environment. Thus, we can test our techniques on any commercially optimized soft keyboards such as Swype [21] or SwiftKey without reinventing the wheel. For consistency, Swype is used for all three techniques, with the auto-correction, text-prediction, and auto-spacing features disabled.

Procedure

First, we explained the tasks to the participants, followed by a demonstration. Participants were then given 5 minutes to practice with each technique, before starting the actual experiment. Participants were instructed to transcribe presented phrases as quickly and accurately as possible, as used in unconstrained text entry evaluation [24]. The ordering of technique tested was counterbalanced. Participants are also allowed to rest whenever they require. On average, it took about 60 minutes to complete the study. Participants were compensated for voucher worth 5 USD.

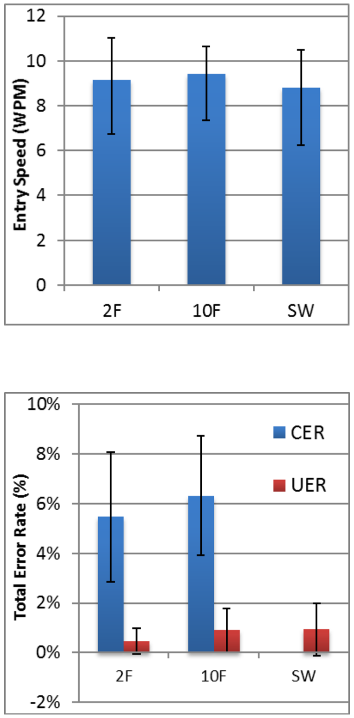

Figure 4: (a) Entry speed and (b) Error rate on Kinect V2. Error bars equal +/- 1 SD.

Study Design

We used a within-subjects design with one independent factor being *technique*. We designed a short study to avoid fatigue. Participants completed 1 session for each technique, where each session consists of 2 blocks of 5 phrases sampled randomly from the Mackenzie and Soukoreff corpus [10]. This resulted in a total of 6 participants x 3 techniques x 1 session x 2 blocks x 5 phrases = 180 phrases.

We analyzed text-entry rate and accuracy. Text-entry rate is measured in Words Per Minute (WPM). The accuracy is measured in total error rate (TER) which consists of corrected error rate (CER) and uncorrected error rate (UER) [24]. However, only uncorrected error rate is included for the shape writing technique due to the difference in measurement of the error rate of word-based technique.

Quantitative Results

Figure 4 shows the mean text-entry rate and error rates for each technique. WPM for two fingers (2F), ten fingers (10F) and shape writing (SW) are 9.16 WPM (SD=1.9), 9.4 WPM (SD=1.2) and 8.78 WPM (SD=1.7), respectively. TERs are 5.9% and 7.2% for 2F and 10F. UERs remain below 1%.

We conducted a one-way ANOVA for WPM and UER. There was no significant effect of technique on WPM (F(2,10)=1.030, p>.05) and UER (F(2,10)=1.265, p>.05).

Follow-up Study (Leap Motion)

We performed a follow-up study using state-of-the-art finger tracking technology (Leap Motion). We use the same procedure and a within-subjects design as the previous study.

We recruited 6 paid students (male) who did not participate in the first study, ages between 22-30 (M=26.2), with no experience of midair text entry nor shape writing technique. Their written English skills were between 2 and 5 (M=3.83).

Quantitative Results

Figure 5 shows the mean text-entry rate and error rates for each technique. Entry rate for two fingers (2F), ten fingers (10F) and shape writing (SW) are 13.76 WPM (SD=4.1), 13.57 WPM (SD=3.9) and 9.92 WPM (SD=3.7), respectively. TERs are 7.3% and 9.4% for 2F and 10F. UERs remain below 1.6% for all techniques.

We conducted a one-way ANOVA for WPM and UER. There was a significant effect of technique on WPM (F(2,10)=14.413, p<.001) and UER (F(2,10)=3.2, p<.05). In the post-hoc analysis, we performed the Scheffe adjustment for equal variance assumption (WPM and UER). There is a significant difference on WPM on all techniques (p<.001) except 2F and 10F. There is no significant difference on UER on all techniques except between 2F and 10F (p<.05).

Discussion

Interactions with midair systems are usually short-lived. Therefore, such systems should be easy to learn and support walk-up-and-use. Our proposed techniques (hunt-and-peck and touch-typing) aim to leverage these advantages because they are familiar to an average computer user.

In terms of novice performance, our results surpass most earlier works on freehand midair text entry that do *not* use controller or markers, except ATK [27], which relies on text prediction and correction whereas our technique does not. Unlike most previous approaches that only allow single character text entry at a time, our approach leverages the dexterity of human hands/fingers and allows bi-manual and multi-fingers text entry. Our results are also comparable to the controller or marker-based approach because our results are on the novice speed (10 trials) instead of expert speed. We expect the entry speed to continue to improve as users become more familiar with the system. For exam-

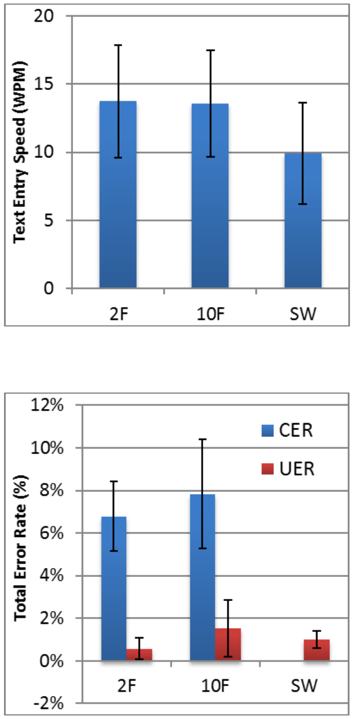

Figure 5: (a) Entry speed and (b) Error rate on Leap Motion sensor. Error bars equal +/- 1 SD.

ple, one of the authors was able to achieve more than 20 WPM (Kinect) and 30 WPM (Leap Motion) using 10 fingers. Nonetheless, our results are still far from the entry speed of touch keyboard (25 WPM) or physical keyboard (60 WPM).

Text entry rates were improved for all three techniques when using a short range sensor with more robust fingertip tracking technology. There is 50.2%, 44.4% and 12.9% improvement each on 2F, 10F and SW, respectively. Our tracking technique on Kinect is rather limited, which suggests a better tracking [22] can improve the performance further. Surprisingly, error rates also increased slightly. One explanation is when using more robust tracking, users tend to be less cautious to the tracking limitations and start typing naturally. This is what we'd hope for in an ideal tracking system. But in a less ideal system, it increases error rates.

Both the touch-based and the midair shape writing are fast [8, 12] for expert users but less so for novice users, as shown in our study. The speed improvement when using a better tracking technology is also limited (only 12.9% as opposed to 50.2% and 44.4% of other techniques). One explanation is that shape writing is a technique that already includes aspects of text-prediction. In addition, it only utilizes a single point to drag over all the characters, thus demanding more arm movement. Therefore, we believe that hunt-and-peck and touch typing have more potential and room for improvement when using even better tracking [22].

It is interesting that there is no significant difference of speed between 2 fingers and 10 fingers, even when using more robust tracking. TiTAN aimed to leverage the memory and motor skill transfer from physical keyboards to midair typing, by allowing them to mimic the typing action on QWERTY layout. However, we observe many users do not use a traditionally correct mapping between fingers and the key (e.g., using left ring finger to hit “q” instead of their pinky finger). Therefore, directly applying touch-typing to midair system by mapping individual finger to a set of characters is actually counter effective for some users. Yet, we are confident that a “true” touch typist would not be affected by this issue and we are keen to explore this in the future. Finally, Feit et al. [4] also found that users using fewer fingers can achieve performance levels comparable with touch typists.

Limitation and Future Work

Our system provides only visual and audio feedback. However, midair interaction is difficult because the lack of haptic feedback leads to input errors, and can suffer from hand tremor and drift. Our participants mentioned difficulty in focusing on four different things: i) presented text ii) transcribed text iii) on-screen pointers and iv) hand pose. Currently, our simple finger tracking technique requires the user to maintain a gap between their fingers. It is also not robust against hand rotation, which causes self-occlusion.

In future work, we aim to improve the tracking [22] and support haptic feedback [2]. We are also interested in studying the learning effect, evaluating the performance of each technique by conducting longitudinal user studies and various UUI interface usability metrics [15]. Finally, we aim to evaluate on how auto-correction and text-prediction can further improve the performance and usability.

Conclusion

In this paper, we presented a prototype midair text entry system for distant display using freehand input. We evaluated the immediate usability of our system, which is implemented using only off-the-shelf hardware. Empirical results show clear usability of our freehand based technique compared to existing methods. Our system is low-cost and has potential to mitigate aforementioned shortcomings with the future development of depth sensor or tracking algorithm.

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