Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Computer Science 00 (2015) 000–000
Procedia Computer Science
www.elsevier.com/locate/procedia

7th International conference on Intelligent Human Computer Interaction, IHCI 2015

Using Hall Effect Sensors for 3D space Text Entry on Smartwatches

Rajkumar Darbar[a,*], Prasanta Kr. Sen[b], Punyashlok Dash[a], Debasis Samanta[a]

[a]*School of Information Technology, IIT Kharagpur, West Bengal, India*
[b]*Center for Education Technology, IIT Kharagpur, West Bengal, India*

Abstract

The use of ultra-small smart devices, such as smartwatches, has become increasingly popular, particularly at the consumer level, in recent years. Smartwatch is a kind of interactive device that offers the ability to read text messages, email and notifications, once it is synchronized with a smartphone. But, performing efficient text input task on smartwatch is really difficult due to its small touch screen display. In this paper, we present hall effect sensors based text entry mechanism that effectively uses the 3D space around the smartwatch for entering alphanumeric characters. Our proposed text input technique (a) does not consume any screen space; (b) does not need any visual search to find a character and (c) does not suffer from fat finger problem.

Keywords: Text entry; smartwatch; mobile usability; hall effect sensors.

1. Introduction

Smartphones became the most ubiquitous computing devices now-a-days. Despite their high portability, it is not possible to provide almost instant access of digital services available in smartphone to users as people typically carry these devices in pockets and bags [1]. To overcome this, concept of smartwatches has been proposed. In the present day context of wearable computing, smartwatches like Samsung Galaxy Gear S, LG G Watch, Motorola Moto 360, Apple Watch etc., are one of the most commercially successful wearable devices. *NextMarket Insights* [2] estimates that over 15 million smartwatches will be sold in 2015 and this number will increase to 373 million by 2020.

Smartwatches allow users to access several applications (messaging, email, calendar, maps) running on smartphones directly from their wrists, without having to look at their phones. Although applications are instantly accessible on the watch, users face difficulties to immediately reply as there is normally no standard text entry method on the same device. To give responses to text notifications on smartwatches, users have to use the voice communication built-in application like Google Now [23] on Android, Siri [24] on iOS. Text input using voice has certain limitations [3] like recognition of voice in noisy environments, eavesdropping on private information etc.

* Corresponding author. Tel.: +91-9635118040;
E-mail address: rajdarbar.r@gmail.com

1877-0509

Recently researchers have invested their efforts to fit virtual Qwerty keyboards either directly or with little modification on smartwatches[4 5]. On-screen keyboards, however, require not only precious screen space but also suffer from the fat finger problem and occlusion.

In this paper, we present hall effect sensors based text entry mechanism that effectively uses the 3D space around the smartwatch for entering alphanumeric characters. In our approach, we placed four hall sensors in four corners of a watch and user draws character gestures (i.e. EdgeWrite[8]) around the device using a proper shaped magnet mounted on his finger. The advantages of our text input technique are (a) no screen space is required (b) no need of visual search to find a character and (c) no fat finger problem and occlusion. A preliminary user-study shows that users are able to enter text faster with a lower error rate.

2. Related Work

In recent-times, text entry on smartwatches is a prospering research area. Small touchscreen of smartwatches suffer from visual occlusion and the fat finger problem. Basically, fingers obscure on-screen contents and UI elements during interaction and as a result it hinders efficient text input on watches. To address these challenges, researchers have investigated various text input methods for smartwatches in last two years.

In paper[4], S. Oney et al. proposed 'ZoomBoard' that uses a miniaturized version of the conventional Qwerty keyboard. The user has to focus on a particular area of keyboard and then tap for zooming into that area. The user can also zoom in further depending upon the number of zoom levels set. Once the zooming is done the user selects the appropriate key by tapping. Although this mechanism seems favorable to the user because of the familiar layout, it still requires two or more careful taps to zoom and select a key. Text entry rates suffer because of these excessive tapping tasks. The 'Swipeboard'[7] divides the traditional Qwerty keyboard into nine regions and to enter any character, user requires two swipes. Using first swipe, user specifies the desired character's region and the second swipe selects the particular character within that region.

In paper[9], H. Cho et al. developed 'DragKey' prototype for text entry in wrist-worn watches with tiny touchscreen. It is a circular keyboard composed of 8 ambiguous keys arranged around the text cursor. At most five letters are assigned to each key. It allows a user to input letters using drag directions regardless of careful touched locations. A user needs lot of time to learn this layout. Furthermore, making continuous drag gestures is quite difficult in walking situations and it is also slower than tapping.

M. Dunlop et al.[6] proposed alphabetic ambiguous-key approach to text entry. They divided the watch screen into seven zones, that is, six big ambiguous keys (three at the top of the screen and three at the bottom) and a center zone for the input entry field. OpenAdaptxt[12] is used for entry disambiguation and input methods like tapping and few swipe gestures are used to change modes (alphabetical/numerical, lower/upper case, punctuation), complete a word or enter a space. Overall, it is good, but a user may face difficulties while trying to enter password and urls. Moreover, commercially available prediction based text input techniques like Minuum[13], Swipe[14], and Fleksy[15] also suffer from similar kind of problems.

Jonggi Hong et al.[5] developed 'SplitBoard' which is a variation of the Qwerty keyboard. Here, Qwerty layout is split into a few layers. The user sees one layer of keys and has to swipe left or right to press keys present in other layers. It is intuitive to use as it doesn't require a steep learning curve. But, the key-size of SplitBoard is not large enough to avoid 'fat-finger' problem.

F.Poirier et al.[11] designed 'UniWatch' derived from the UniGlyph[16] method and it supports text input on smartwatches using only three keys i.e. diagonal-shape key ('/'), loop-shape key ('(') and straight-shape key ('|'). In paper[17], J. M. Cha proposed Virtual Sliding Qwerty (VSQ) keyboard which utilizes a virtual qwerty layout and a 'Tap-N-Drag method to move the qwerty keyboard until the target letter is shown on the screen.

The keyboards, discussed so far, require significant amount of space in the watch display. More recently, Funk et al.[10] explored a new text entry method for smartwatches using a touch sensitive wristband. This technique does not need any screen space and thus watch's screen can be used for presenting actual content.

However, hall effect sensor and magnetometer for input have also been explored in the context of different devices. Karunanayaka K. et al.[22] developed an innovative pointing interface for computers by tracking 3D position of a finger worn neodymium magnet over a hall effect sensors grid. In paper[19], Ke-Yu Chen et al. presented uTrack that turns the fingers and thumb into a 3D pointing input system for wearables using magnetic field sensing. Abracadabra[20] extends interaction off the watch display using watch's inbuilt magnetometer sensor and a magnet mounted on a finger. Unfortunately neither of these papers include text entry mechanism. In paper[21], H. Ketabdar et al. introduced MagiWrite, which supports 3D space digit (i.e. 0 - 9) entry in smartphones using magnetic field based around device interaction technique. In this approach, user draws digit shape gestures in front of the device using a properly shaped magnet taken in hand. This magnet movement changes temporal pattern of magnetic flux around the device and it is sensed and registered by the magnetometer sensor. Then, they applied Dynamic Time Warping (DTW) algorithm to recognize a particular digit from this unknown magnetic flux pattern. But this approach does not work properly due to the variation in earth's magnetic field at different locations.

3. Text Input Using Hall Effect Sensors

3.1. Proposed framework

To avoid fat finger and occlusion problems during text entry on smartwatches, we develop hall effect sensors based text input mechanism that effectively uses the 3D space around the device for entering alphanumeric characters. For this purpose, four hall sensors are placed in four corners (marked as 1, 2, 3, and 4) of a watch and the user draws characters' gestures around the device using a magnet (may be ring or disk type) mounted on his finger (see Fig.1(*a*)). These hall sensors become active when a magnet comes into their sensing range. Our proposed technique adopts the EdgeWrite[8] mnemonic gesture-set for alphanumeric input. In short, EdgeWrite is a unistroke method originally designed for stylus entry on PDAs by people with tremor. Here, we mapped each EdgeWrite letter to four corners. For example, using the author's labels for the corners, the corresponding corner-sequences of the letters 'A', 'N' and 'D' are '132', '1423' and '3212' respectively and it is shown in Fig.1(*b*). Table 1 represents the corner sequences of 26 alphabets and 10 digits. Note that, we modified the corner sequences of three characters ('E', 'K' and 'P') for user convenience. However, there are two more corner sequences, that is, '12' and '21' for spacebar and backspace key respectively. To enter any alphanumeric character, users move their magnet mounted finger over hall effect sensors following those corner sequences mentioned in Table 1. If the drawn corner sequence matches with the previously stored corner sequence pattern, then system recognizes the intended character.

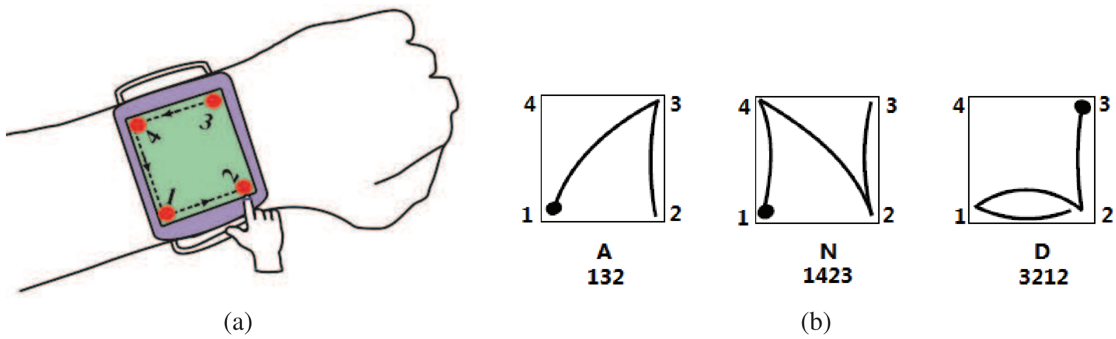

Fig. 1: (a) Positions of four hall effect sensors in four corners of a watch and user is trying to write 'C'. (b) Three EdgeWrite characters and their corner sequences. The dots mark the starting points.

This around device interaction based text entry method requires a solution to the segmentation problem, since there is no 'stylus lift' event which is available in touchscreen interaction. Thus we follow a Δ time-instant for segmenting two consecutive character gestures. If a user passes his finger over any two hall sensors within Δ time period, then our system understands that user is trying to follow the corner sequence pattern of a particular character or number. Otherwise, it recognizes the previous corner sequence and segmentation occurs, that is, user is going to enter next alphabets or numbers. In our experiment, we empirically choose the value of Δ as 950 msec.

Table 1: Alphanumeric characters and its corner sequences.

Characters	Corner sequences	Characters	Corner sequences
A	132	N	1423
B	4121	O	34123
C	3412	P	1434
D	3212	Q	34323
E	13412	R	143
F	341	S	3421
G	34321	T	432
H	4132	U	4123
I	41	V	413
J	321	W	41323
K	3142	X	4231
L	412	Y	4232
M	14232	Z	4312
Numbers	**Corner sequences**	**Numbers**	**Corner sequences**
0	32143	5	34121
1	32	6	3121
2	43212	7	431
3	4321	8	34213
4	41232	9	3432

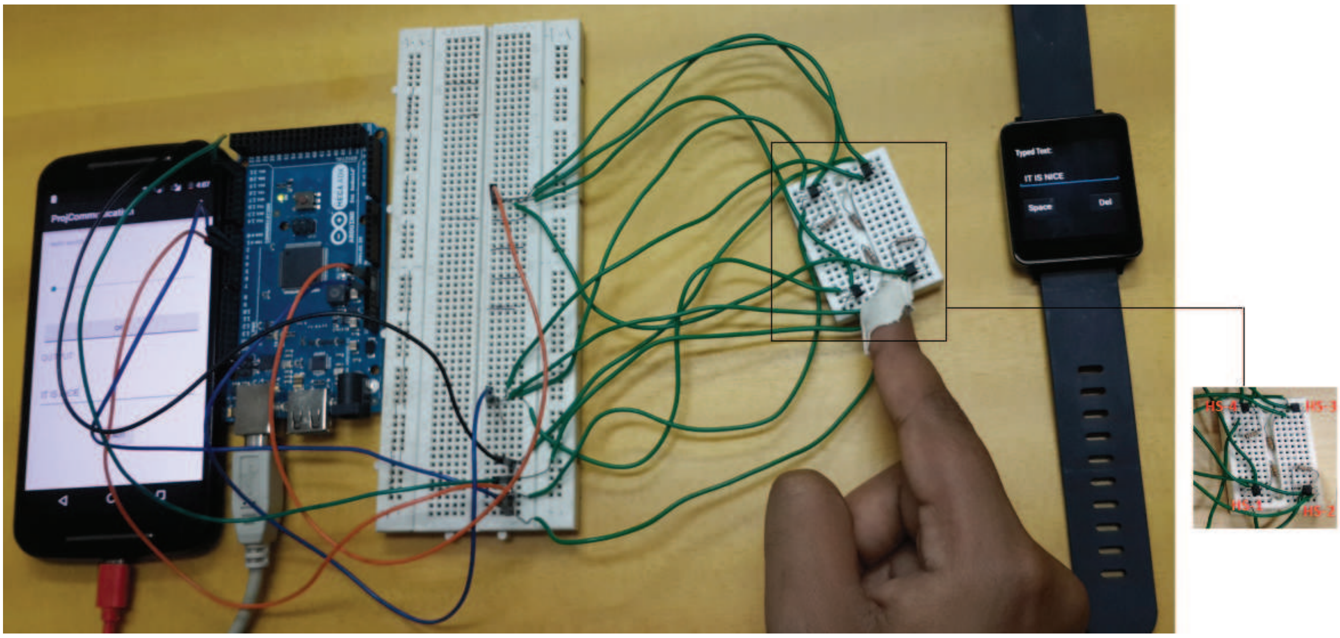

Fig. 2: Prototype of our proposed text entry mechanism for smartwatches. Here, ‘HS’ (red color text in the rightmost image) represents hall effect sensor. Using this setup, user is trying to write ‘IT IS NICE’.

3.2. Implementation

To realize our proposed text input technique, we place four A3144 hall effect sensors in four corners of a mini bread-board (dimension: 47mm × 35mm × 8.5mm and it is almost equivalent to a smartwatch touchscreen display) and mount N54 grade, disk-shaped (10mm × 3mm in diameter and height respectively) neodymium magnet on the finger using a small strip of velcro. Hall sensors are connected to an Arduino micro-controller via an electrical circuit. On the other-side, the Moto G (with Android OS version 5.1) smartphone is connected to the Arduino via a USB

OTG cable and it is also paired with LG W100 smartwatch (with Android Wear version 4.4W) over bluetooth. The complete setup is shown in Fig.2. When a user brings his magnet mounted finger near to a hall sensor, then it becomes active and sends its value to the Arduino. Then Arduino recognizes the intended character/number by matching with the predefined patterns and transmits it to the phone's Android application. Finally, the entered character/number is transferred from the phone to the watch's application and appended to a text-field.

4. Experimental Evaluation

This section presents the results of the experimental evaluation we conducted with participants. We first describe how we designed and conducted the experiments and then we report the results of our evaluation.

4.1. Method

To evaluate the feasibility of our proposed text input method, we performed some text typing tests and compared it with Qwerty layout available in Samsung Gear S. Five university students were recruited (3 male and 2 female), all aged between 20-28 (Mean = 24). The participants were primarily post-graduate students in our university's Information Technology department. None of them had any previous experience with smartwatches, but they are all well experienced with smartphones and accustomed with typing using phone's default Qwerty soft-keyboard.

Before the beginning of the actual tests, a demo session was conducted to educate the participants about the hall sensors based text input mechanism. In the demo session, each participant were asked to type in their names, surnames, addresses and telephone numbers with the proposed technique. This was done to familiarize the participants with the system further, on a personal level. Following this practice session, each user spent almost 40 minutes for two sessions using the system to enter phrases, and finally answered a brief questionnaire and informal feedback. The second system was then tested in the same way. The evaluation was conducted in a calm lab environment.

For actual evaluation purposes, a total of 10 phrases were selected at random from the MacKenzie and Soukoreff[18] texts. This same phrase set was used by all participants for each system. During the test, phrases were displayed to the users on a desktop screen. Participants were able to rest whenever they wished, but were encouraged to rest between phrases rather than mid-phrase. During typing, they were allowed to correct any errors they made, but a constraint was imposed upon them. The constraint is that they were allowed to correct an error, only if they observed it at the time of committing the mistake. So, if they typed along and realized later that they had made an error in a previous word or the beginning of the word they were typing, they weren't permitted to rectify the mistake. One more typing constraint is that users were not allowed to use word-prediction, although it was available in Gear S.

4.2. Results

In the experiment, text entry performance is measured in terms of WPM (words-per-minute) and TER (total error rate). Note that, we recorded the corrected WPM measure and not the raw WPM measure as it would have included incorrectly typed characters during the calculation. The WPM is calculated as $\left(\frac{\text{characters per minute}}{\text{5 characters per word}}\right)$ and TER as $\left(\frac{\text{INF + IF}}{\text{C + INF + IF}}\right)\times 100\%$; where INF is incorrect not fixed characters, IF is incorrect fixed characters and C is correct characters. The results for WPM and TER are shown in Fig.3(a) and (b). On average, participants entered the phrases with 5.78 WPM (SD=0.45) using the Qwerty keyboard and 3.9 WPM (SD=0.36) using the proposed text input method. A t-test shows that two technique had a signifcant effect on the WPM (p=0.02). The TER using the Qwerty keyboard was 22.12 (SD=3.43) and 6.4 (SD=2.62) for our proposed technique. This improvement in TER is significant (p=0.05). Therefore, our proposed technique provides acceptable typing speed with minimum error compare to Qwerty layout.

4.3. Questionnaire Results

After end of each session, we asked participants to give their valuable feedback to a questionnaire comprised of ten statements on a 5-point Likert scale (1 = strongly disagree , 5 = strongly agree). Our proposed text input method was rated significantly higher than Qwerty keyboard. Majority (i.e. six out of ten) feedbacks were in favor of our developed system. Table 2 represents the list of statements, mean responses, and significant differences. Moreover,

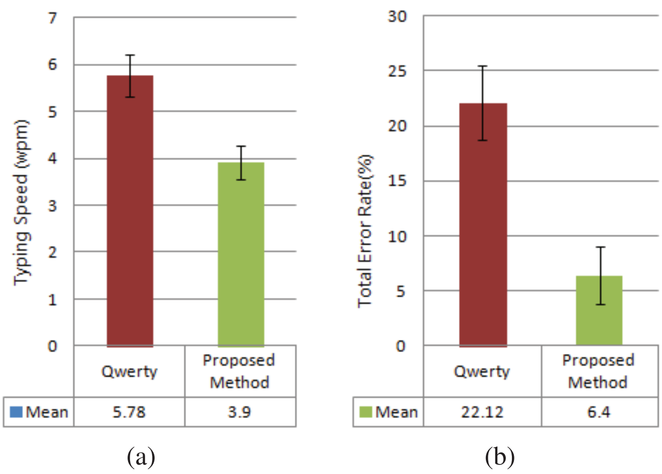

Fig. 3: (a) The average WPM for the Qwerty and Proposed Method. (b The average TER for the Qwerty and Proposed Method. In both figures the error bars show the standard deviation.

users also reported few informal feedbacks. For example, one female user said that she got confused between character ‘O’ and number ‘0’ most of the time. One male participant stated that he also did same kind of mistake while writing ‘K’ and ‘X’. Some users mentioned that they wanted to write punctuation symbols using this system.

Table 2: Questionnaire results (mean, sd) for responses given on a Likert scale (1 = disagree strongly, 5 = agree strongly).

Statement	**Qwerty**	**Proposed Text Input Method**
Easy to use	3.2 (1.12)	**4.3** (**0.51**)
Fast to use	2.6 (0.34)	**4.4** (**0.33**)
Easy to learn	4.2 (0.12)	4.0 (0.24)
Improve with practice	3.3 (0.75)	**4.4** (**0.54**)
Felt in control	3.0 (0.44)	**3.8** (**0.38**)
Easy to undo mistake	4.1 (0.32)	3.9 (0.20)
Mental demand	2.5 (0.11)	4.4 (0.23)
Physical demand	2.4 (0.14)	3.9 (0.28)
Frustration	3.5 (0.18)	**2.2** (**0.08**)
Performance	3.1 (0.33)	**4.2** (**0.36**)

5. Conclusion

In this paper we introduced hall effect sensor based text input mechanism for smartwatches. This technique does not require any touchscreen space and visual search to find a character, but demands little cognitive load. User study reported that proposed method can well balance between typing speed and error rate. This technique easily overcomes the ‘fat-finger’ problem. Here, we did a small-scale user study in controlled environment, but in future (a) we will build a fully integrated system inside a watch and will investigate other usability aspects of our proposed technique (b) we are also planning to use proximity sensors instead of hall effect sensors to avoid the mojor concern of carrying an extra magnet on finger.

References

1. Wiese, J., Saponas, T. S., and Brush, A. Phoneprioception: enabling mobile phones to infer where they are kept. In Proc. CHI'13, 2157-2166.
2. Siegal, J. Smartwatch sales set to explode, expected to top 100 M within four years, BGR 2013. `http://bgr.com/2013/09/27/smartwatch-sales-forecast-2020/`.
3. Sawhney N. and Schmandt C., Nomadic Radio: Speech and Audio Interaction for Contextual Messaging in Nomadic Environment, ACM Trans. Comput.-Hum. Interact. 7(3), 2000, 353-383.
4. Oney S., Harrison C., Ogan A., Wiese J., ZoomBoard: A Diminutive QWERTY Soft Keyboard Using Iterative Zooming for Ultra-Small Devices, In Proc. CHI 2013, 2799-2802.
5. J. Hong, S. Heo, P. Isokoski, G. Lee, SplitBoard: A Simple Split Soft Keyboard for Wristwatch-sized Touch Screens, In Proc. CHI 2015, 1233-1236.
6. M. D. Dunlop, A. Komninos, N. Durga, Towards High Quality Text Entry on Smartwatches, In Proc. CHI 2014, 2365-2370.
7. X. Chen, T. Grossman, G. Fitzmaurice, Swipeboard: A Text Entry Technique for Ultra-Small Interfaces That Supports Novice to Expert Transitions, In Proc. UIST 2014, 615-620.
8. J. Wobbrock and B. Myers, Trackball text entry for people with motor impairments. In Proc. CHI'06, Pages 479-488.
9. H. Cho, M. Kim, K. Seo, A Text Entry Technique for Wrist-worn Watches with Tiny Touchscreens, In Proc. UIST 2014, 79-80.
10. M. Funk, A. Sahami, N. Henze, A. Schmidt, Using a Touch-Sensitive Wristband for Text Entry on Smart Watches, In Proc. CHI 2014, 2305-2310.
11. F. Poirier and M. Belatar, UniWatch - Some Approaches Derived from UniGlyph to Allow Text Input on Tiny Devices Such as Connected Watches, In Proc. of HCII 2015, 554-562.
12. Montaparti, S., Dona, P., Durga, N. Meo, R. D., OpenAdaptxt: an open source enabling technology for high quality text entry, In Proc. CHI'12.
13. Minuum keyborad, `http://minuum.com/`
14. Swipe keyboard, `http://www.swype.com`
15. Fleksy keyboard, `http://fleksy.com`
16. Poirier, F., Belatar, M., UniGlyph: only one keystroke per character on a 4-button minimal keypad for key-based text entry. In Proc. of HCI International 2007, 479483.
17. J. M. Cha, E. Choi, J. Lim, Virtual Sliding QWERTY: A new text entry method for smartwatches using Tap-N-Drag, Applied Ergonomics, Vol.51(2015), 263-272.
18. MacKenzie I. S., Soukoreff R. W., Phrase Sets for Evaluating Text Entry Techniques, In Proc. CHI 2003, 754-755.
19. Ke-Yu Chen, Lyons K., White S., Patel S, uTrack: 3D Input Using Two Magnetic Sensors, In Proc. UIST 2013, 237-244.
20. Harrison C., Hudson S.E., Abracadabra: wireless, highprecision, and unpowered finger input for very small mobile devices. In Proc. UIST 2009, 121-124.
21. H. Ketabdar, M. Roshandel, K. A. Yksel, MagiWrite: Towards Touchless Digit Entry Using 3D Space Around Mobile Devices. In Proc. MobileHCI 2010, 443-446.
22. Karunanayaka K., Siriwardana S., Edirisinghe C., Nakatsu R., Gopalakrishnakone P., Magnetic Field Based Near Surface Haptic and Pointing Interface, In Proc. HCII 2013, 601-609.
23. Google Now, `https://www.google.com/landing/now/`
24. Apple Siri, `http://www.apple.com/in/ios/siri/`