InclineType – An Accelerometer-based Typing Approach for Smartwatches

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ABSTRACT

Small mobile devices such as smartwatches are a rapidly growing market. However, they share the issue of limited input and output space which could impede the success of these devices in future. Hence, suitable alternatives to the concepts and metaphors known from smartphones have to be found. In this paper we present *InclineType* a tilt-based keyboard input that uses a 3-axis accelerometer for smartwatches. The user may directly select letters by moving his/her wrist and enters them by tapping on the touchscreen. Thanks to the distribution of the letters on the edges of the screen, the keyboard dedicates a low amount of space in the smartwatch. In order to optimize the user input our concept proposes multiple techniques to stabilize the user interaction. Finally, a user study shows that users get familiar with this technique with almost no previous training, reaching speeds of about 6 wpm in average.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Input devices and strategies (e.g., mouse, touchscreen); Graphical user interfaces.*

General Terms

Interaction Techniques, Fat-finger-problem, Input Concepts, Keyboards, Mobile Devices, Acceleration Sensor.

Keywords

Small Devices, Smartwatch, Input Techniques, Text Entry, Fitts' Law, Wrist, Angle, Inclination.

1. INTRODUCTION

Smartwatches and other related wearables are becoming more popular. The launch of Apple Watch is expected to be the element that helps these devices to become mainstream. Many of those devices have a minimalistic UI and rely on speech for more complex input. Unfortunately, dictation is inherently a non-private task, and both sensitive information and public spaces are usually not suitable for speech input. Thus, typing in wearables is a requirement for many tasks.

The fat finger problem (e.g., [10]) is relevant to smartphones and even more prominent for smaller devices such as smartwatches. Since text input is required even for simple tasks such as answering a message, however, the common input technique present in Android Wear-based watches or Apple Watch (voice dictation) cannot be used in a broad range of situations, e.g., due to privacy. To overcome this limitation, some smart input techniques have been proposed. In this paper we focus on smartwatches, and present a method for input that makes use of a 3-axis accelerometer sensor. Our technique lets the user type by selecting a key using wrist movements, and single taps. We have performed an initial user study to determine the feasibility and the performance novice users may achieve with such approach.

2. RELATED WORK

Typing in devices without hardware keyboards such as the classical buttons of conventional Blackberry devices may lead to low typing performances. This issue can be partially alleviated using high profile predictive and correction techniques (e.g., Minuum, Swype, Fleksy…). However, even the excellent results of these techniques, they are still not perfect and may erroneously *correct* properly spelled words such as road names, main names etc. Moreover, some of them rely on the use of the relative large sizes of the mobile devices. For smartwatches, the typing is an even more difficult task.

For small devices such as watches, the techniques tailored to improve input follow two tendencies: adding hardware that makes the interaction richer, or make smarter keyboards. Our method falls in the second category. Small devices can be enhanced for input by adding sensitive back covers [1]. However these back-of-device interactions would require to take the smartwatch off.

Figure 1: Typing by inclination of smartwatch.

Other proposals include adding joystick sensors for panning and tilt detection [13]. However, it is unlike that all vendors will include these by default in mainstream consumer devices, which are our target devices.

Tilting ([7]) has previously been introduced to input detection both as a full typing solution with a WiiMote [5]. But this solution relies on the use of an external screen. It has also been used to disambiguate buttons in old feature phones [12], where the users had to tilt the device while pressing a button. It has also been used in conjunction with specialized hardware [8]. Our approach is similar in spirit to this one, but using a consumer device instead of customized hardware for the key recognition.

Finally, pure soft solutions create advanced keyboards. Similar to Minuum, Dunlop et al. [4] divide the screen in regions that group several keys and let the user tap on these regions. A powerful disambiguating software makes the rest to type correctly. Zoomboard is a keyboard that requires two taps for key selection. The keyboard is presented in reduced size, and the first tap on a region generates a zoom-in on that region. The second, respectively third tap effectively selects the key. Leiva et al. [6] compare the Zoomboard to other techniques such as the offset cursor and offset zoom and found that Zoomboard was a solid proposal for small screens, with speeds of 6 wpm in screens of 18mm. Another alternative to Zoomboard is Swipeboard [2]. This last approach uses swipes instead of taps. Initially, the screen is divided in regions with three to four keys, and a swipe activates one of the regions. A second swipe selects the key among the remaining ones. The main advantage is that it does not require precision because it is target agnostic, and they improve slightly over Zoomboard in wpm.

In contrast, our approach allows to select all letters of the alphabet solely by changing the angle of the user's wrist and a single tap on the screen. There is no need for extra hardware or multiple steps to enter a letter. Additionally, it works reliably without the use of automatic spell checking. Hence, uncommon strings can be entered easily.

3. OUR APPROACH

In our approach we rely on sensors for measuring the devices' inclination which are already built in several consumer smartwatches. One of our design goals was to facilitate the intuitive feeling of gravity to select an alphabetic letter. Another goal we addressed was to allow direct selection of letters with only one interaction step.

In our approach the alphabets letters are arranged clockwise manner along the screen borders (see Figure **Figure** 1). Depending on the inclination of the smartwatch caused by raising and lowering the elbow relatively to the wrist (x-axis) as well as the rotation of the wrist along the forearms axis (y-axis), a specific letter can be selected. The currently selected key is presented in a highlighted fashion in order to support the user. If neither in x-axis nor in y-axis a significant inclination is detected, the space character is chosen. In this case, no letter is highlighted. Beside the alphabet characters, the period is presented and a hat character which allows to switch to capitalized characters, figures, and special characters. By tapping on an arbitrary point of the smartphone's touchscreen, the user enters the selected letter. On the contrary, long tap induces a backspace to delete accidentally typed errors.

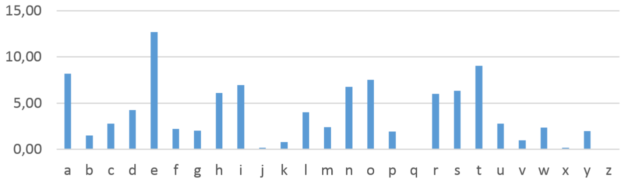

Figure 2: Letter frequencies in English sentences according to [2].

Turning the wrist around a given point completely without inclination to select individual letters may have multiple disadvantages. First, the legibility of the screens contents considerably decreases when the user's visual axis diverts too much from the screens orthogonal. Secondly, forcing the users to hold the smartwatch constantly in an inconvenient position may be tedious. Hence, we implemented a null calibration feature to let the user decide (i) which is the preferred null position, and (ii) how sensitively the rotation around the x- and the y-axis affects the selection of letters.

In our first test runs during the design stage we discovered that minor changes in the smartwatches inclination often resulted in frequent unattended changes in the selection of two neighboring letters. Since this may severely impede the selection of the desired letters, our design includes the implementation of a hysteresis for the selection of letters which allows a smoother interaction.

Another point we discovered in the design stage of our approach was that there was often a difference between the desired letter and the letter which was actually entered by the users. This discrepancy was caused by the inherent design of our interaction, i.e., selection by inclination and tap for entering the letter which often induced slight changes in the inclination before the tap was detected. A simple but effective technique eliminated this issue: as a jitter prevention we recorded the interaction for selecting letters in a circular buffer for the timespan on 100ms. When a tap on the touchscreen was registered, the letter entered was the one that had been selected this timespan ago. Thus, more reliable inputs were possible even when the user was jittering during the touch input.

Alternative arrangements of letters

Letters are selected depending on the angle computed from the inclination of the x- and y-axis. Hence, in the first version introduced so far, we assume that the index of difficulty (according to Fitts' law) to select an arbitrary letter is equal. Beside the conventional approach to distribute the alphabets letters uniformly at the corners of the smartwatches display, we also implemented a version which is optimized regarding the Fitts' law [4]. This principle assumes that the difficulty to hit a target mainly relies on the target's distance and size. It has already

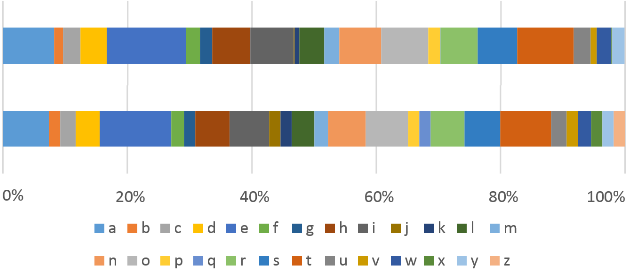

Figure 3: Distribution of letter frequencies and reserved space in respect of Fitts' law. Parts of bar representing according to actual letter frequencies (upper bar), and adapted version (lower bar) which maintains a minimum size for letters of low frequency.

been considered for a study on tilt-based interaction by MacKenzie et al. [7] based on tablet computers. They used a virtual ball as input metaphor and provided 12 target regions (virtual holes). The users had to steer the ball towards these holes in a defined sequence. Whilst varying the size of the targets, they measured the time the users needed. They pointed out that Fitts' law can be applied to tilt-based interaction.

This motivated us to consequently adapt this principle to our approach. Since the inclination of the smartwatch always selects one specific letter the distance measure can be neglected. However, based on the fact that letter frequencies [11] are not equally distributed (see Figure 2) we adapt the targets' sizes (letters) according to their frequency. Directly adapting the letter frequencies to the size of selection revealed that it is nearly impossible to select rare letters such as j, q, x, z (see Figure 3 upper bar). Hence, we preserved a minimum size for these letters which proportionately decreased the influence of frequent letters (see Figure 3 lower bar). The actual arrangements of letters for both alternatives can be seen in Figure 4.

Figure 4: Normal target size for letters (left) and adjusted target sizes (right) depending on letter frequencies.

4. RESULTS

As proof of concept our approach has been implemented on a fully functional Android 4.2.2 smartwatch (Umeox KingKong Pro) with an integrated Bosch BMA050 3-axis accelerometer. Its 1.6 inch TFT screen has a resolution of 240x240 pixels.

We implemented an experimental application including the features for null calibration, hysteresis and jitter prevention. The smartwatch app allowed to switch between both alternatives of letter arrangements. We extended the experimental app by a logging feature which recorded the start and end of individual tests as well as each keystroke. Using the experimental application we tested the feasibility in a preliminary user study. Our user study was carried out with 11 test participants (3 females), with ages ranged between 21 to 37 (avg. 27.6±4.8) years which obtained a short explanation about smartwatches and both the input concepts using the uniform distribution of letters (standard version) as well as the distribution depending on letter frequencies (optimized version). Subsequently, the participants had the opportunity to test the input concepts for a short period (≤3 minutes). Additionally, they were free to decide whether they wanted to use an aclinic null position or they wanted to calibrate the null position to a convenient inclination of their wrist.

Both variants (standard and optimized version) were tested with the participants. The users had to type in a short sentence whereas the timings of the user input were logged. In order to limit learning effects, we alternated the order of the first version to be tested, i.e., if the standard or optimized version was tested in the first or the subsequent turn. We analyzed the automatically recorded data by Student's paired-sample *t*-test to evaluate our experiment.

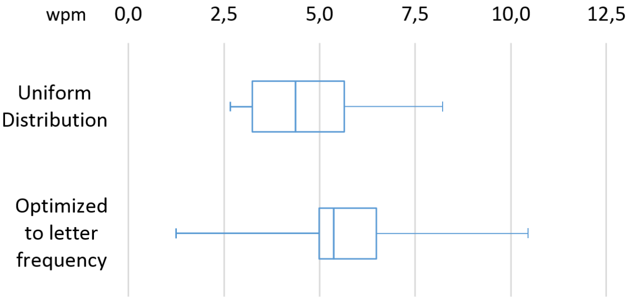

Figure 5: Performance in words per minute for both the standard version with uniform distribution of letters (top) and the optimized version (bottom).

We tested our null hypothesis H_0: *The optimized version (according to Fitts) of our implementation is not performing better (in terms of words per minute) than the standard version (uniform distribution of letters)*. The arithmetic mean as well as the median of the optimized version (M=5.9, SD=2.43) showed a better performance (see Figure 5) than the standard version (M=4.7, SD=2.18). In average the optimized version allowed ~25% faster typing than the standard version. This difference in the performance of both versions of our user study was significant: $t_{10}=-2.105$, $p=.030$. Hence, H_0 can be rejected for this preliminary user study. Most of the users preferred the optimized version and reported the subjective feeling that this version allows a more convenient typing. Furthermore, the participants mentioned that a blinking cursor would have been advantageous, especially when space characters have to be entered. Which was in fact a shortcoming of our user test design – and could be easily implemented for future tests. Although they liked the possibility to calibrate the null position to arbitrary wrist inclinations most of them preferred the aclinic setting for the test. A possible explanation to this fact could be that they are used to recognize aclinic surfaces (e.g., water surface in a glass of water). In future studies a visual indicator for the null position should be included.

5. DISCUSSION

In this paper we introduced a novel input concept for typing by inclination of smartwatches without the need to press one or multiple hardware buttons concurrently. Our approach proposes multiple techniques for the stabilization of the user interaction.

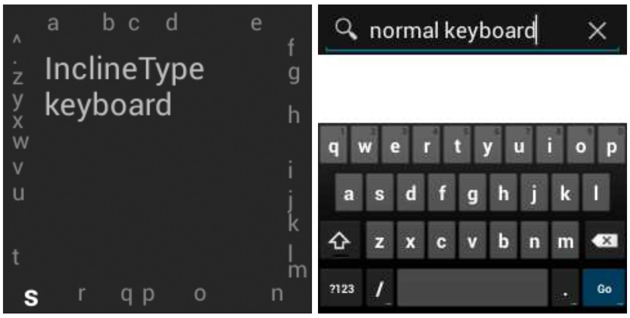

Figure 6: Relatively low space consumption and rectangular input by InclineType (left). Standard keyboard input consuming large screen area (right).

Additionally, we addressed the fact that letter frequencies are not distributed uniformly and adapted this to our concept according to the Fitts' law. Our technique is not dependent on dictionaries, i.e., arbitrary character strings can be entered at the same speed than well-known words. Another advantage of our concept is that this method occupies less screen space than the conventional input and the remaining screen space may stay squared (see Figure 6). Compared to voice input there are no privacy issues. Finally, the feasibility of our concept has been verified by an experimental application as well as a preliminary user study.

In this paper we only addressed the English language. As there also exist studies about letter frequencies of other languages (e.g., [9]), our concept could be transferred to them as well, as long as a minimum character size can be maintained. The support of languages with significantly more than 27 letters, e.g., the Chinese language would need to take additional effort (e.g., multiple interactions), but this applies also to other input methods.

Our approach has rather high requirements to motoric skills of the users. Hence, it is likely that persons with motoric impediments will not be able use this technique. The same issue may exist in very unsteady or turbulent environments. However, the authors assume that other approaches will have similar issues.

Some techniques of the related work need to train the users to an excessive extent. A design goal of our approach was to make it explicitly intuitive. Our preliminary user study aimed at testing untrained users and we obtained the unanimous feedback that this technique is very intuitive. However, testing completely untrained users resulted in mediocre performance for typing speed, compared to some of the approaches of the related work which partially trained their test users intensively. Since our approach allows interaction with minimized interaction steps and the letters are always presented in a consistent manner our technique leverages people's spatial memory. Thus, it is likely that well-trained users will be able to perform much better in typing speed and error rate.

Similar to other approaches this technique could be extended by automatic spell checking. Dependent on the concrete application this could significantly improve the typing performance, but as stated before, this may impede the input of arbitrary character strings.

6. FUTURE WORK

We plan to carry out a comprehensive user study giving the tests users the chance to practice our alternative concept for text input for several hours. As it has been shown in other studies, we expect a significant increase in typing speed by experienced users. This user study will include an in-depth comparison of both alternatives of character arrangements to verify if our implementation of Fitts' law shows an optimization in users input performance.

Watches may be worn either on the wrist of the dominant hand or the other hand. For longer texts, some users could prefer to hold the smartwatch in both hands. Since these different application scenarios could significantly affect the input performance, our planned comprehensive user study will compare these variations.

Beside existing smartwatches, currently many other devices appear on the market which could be used in conjunction with future smartwatches. One of these devices is called *Myo* which is a gesture control armband which uses electromyographic sensors to detect arm and hand gestures. Although it is already possible to connect such a device by standard Bluetooth, in future smartwatches these muscle sensors could be integrated into the smartwatches armband. Our future work focusses this combination of hardware in order to optimize our input concept for replacing the touch interaction by muscle actuation in order to further improve the input performance of our concept.

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