Method for Text Entry in Smartwatches Using Continuous Gesture Recognition

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***Abstract*—This work proposes a method that allows the entry of text in smartwatches using gestures based on geometric forms. For this it is proposed the development of a prototype capable of inserting a letter with no more than two user interactions. Gesture recognition is performed using the incremental recognition algorithm. A set of gestures with lines and curves were created to be recognized by the incremental recognition algorithm, generated from the reduced equation of the line and the reduced equation of the circumference, respectively. After recognizing the gestures, they are sent to a classifier *Naïve Bayes* which is responsible for predicting the letter that will be inserted. The Naïve Bayes classifier was trained with a user gesture base that drew all the letters of the alphabet using only the gestures available in the set presented to them. Using the gesture base and the classifier *Naïve Bayes* a prototype was developed for smartwatches that automatically suggests the most likely letters to be inserted. The prototype was used to perform an experiment, during the experiment the users inserted the five most frequent letters and the five less frequent letters of the English language. The results of the experiment show that the prototype is able to recognize a letter with at most two interactions between the user and the smartwatch. The analysis of the usability and experience test shows that the prototype has generalized potential for use, since it allows the entry of text with up to two interactions and with a 100% hit rate for the most frequent letters and 95,14% For less frequent letters.**

***Keywords*—Smartwatch; Text Entry; Gesture Recognition; Machine Learning; Continuous Gesture Recognition.**

I. Introduction

Mobile computing has gained space in the market because the need for communication has increased considerably and is growing steadily, and keyboards have been created for these devices and then applications that allow text entry by touching the screen [7].

Smartwatch is a smart mobile device in the shape of a clock, which can work in conjunction with a smartphone, making everyday things easier, as everything is available in a small screen attached to the wrist of the user. Although there are several text input searches for smartwatches, because they are small, they make this task difficult [1, 3, 12, 11]. In this sense, the interaction with these devices is still a challenge, since their intention was to facilitate the life of the user. Therefore, it would be necessary to create fast and efficient ways of interaction, among them, the text input techniques [5, 13].

Considering this problem, this work proposes the development of a method for gesture-based text entry for devices with reduced touch screens, with the intention of inserting a letter without the user having to draw it completely and perform tests Usability and experience of the proposed method. To do so, it will be necessary to specifically recognize gestures, identify gestures necessary to insert letters and recognize letters with up to two interactions, create an interface for smartwatches using the proposed method, develop and apply usability and experience testing.

In this way, the following results are presented during the development of this work: creation of an Android application used to construct a gesture base, a study of the most frequent lyrics of the Portuguese language and creation of a prototype using the Naïve Bayes classifier.

The next sections present contents that are relevant to the understanding of the partial results obtained. The next section discusses the related works. In sequence will be approached the materials and methods and details on the realization of the experiments. Afterwards, the final results will be discussed.

II. Related Work

Devices that do not have physical keyboards have a higher rate of learning difficulty among users, since instead of physical keyboards, there are applications that are responsible for this function [4, 6].

The Fleksy keyboard was developed for Android devices and is used on devices of all sizes. It not only analyzes the keys, but also the writing pattern and the nearby keys to identify the word.

In the case of Zoomboard, a method can be played in the area of the desired letter and an enlargement of this is presented to the user to be enlarged again or to allow the user to select [13].

Google Gesture Search allows the user to draw letters and numbers to search the device.

Another application, the Google Handwriter Input, allows you to enter text into the device using italic letters.

Analog Keyboard has an area where you can draw a letter and predict words.

0730-3157/17 $31.00 © 2017 IEEE
DOI 10.1109/COMPSAC.2017.168

Fig. 1. Left-hand model and right-hand segments generated by the incremental recognition algorithm. Adapted from [8].

In the case of Minuum, created for use in devices with reduced screens, it is an application that puts all the letters in a single row and, to write, the user must touch them, which performs the text prediction.

WearWrite is an application that allows you to write articles in a collaborative way, in which the user can send or accept notifications directly from his *smartwatche* [11].

In our previous work, we proposed a prototype for a text input method in smartwatches based on geometric shapes. This prototype aims to allow the user to insert a letter with up to two interactions using geometric shapes [10].

All works are aimed at facilitating text input on mobile devices. Considering the possibilities of these applications for text input, the purpose of this work is to propose a method that allows the insertion of a letter with only one or two touches on the screen using gestures, it is also proposed a usability test with users to validate The proposed method.

III. Materials and methods

A. Incremental Gesture Recognition

The incremental gesture recognition algorithm developed by Kristensson and Denby [8] works in a way that a gesture can be recognized even if it has not been finalized, since it works with the continuous recognition of gestures and is able to predict them with High precision in several different data sets.

By being able to predict partial gestures, the algorithm can recognize a gesture before it is complete, so it is possible to have a continuous feedback.

For this, it uses a technique that consists of the authors in models and segments. Thus, each gesture is a model that has a set of segments describing, in an increasing way, the partial stretches of the movement.

Because it is a vector of ordered points in relation to time, ie a vector of ordered points relative to the way the movement is to be produced, a gesture is segmented in several parts and in increasing movements. Fig. 1, exemplifies this technique.

A model represented by w is a pair (l, S), where l is the model description and S is a set of segments that describes the complete model. Equation 1 describes a complete model ordered in relation to time [8].

$$S = [s_1, s_2, ..., s_n]^T \tag{1}$$

B. Naïve Bayes

Naïve Bayes is a classifier that works with the concept of conditional probability. It considers the attributes conditionally independent. Despite this, it is widely used, has good results and requires a small amount of training data [2, 15]. Its operation is class-based and for classification uses conditional probability and Bayes's Theorem [2, 14].

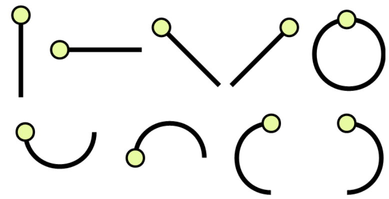

Fig. 2. Set of gestures created to be recognized by the algorithm of incremental recognition and to be used for letter insertion.

The Naïve Bayes classifier works with classes, so based on the characteristics of each element, the classifier calculates the probability of this element belonging to a particular class of its training set [2]. Calculation of the probabilities is performed using the Bayes theorem, represented in Equation 2:

$$P(C_k|x) = \frac{P(C_k)p(x|C_k)}{P(x)} \tag{2}$$

C. Base Construction

A 30-user test was performed to identify patterns between letters. In this way, a base of gestures to be recognized was created, which is composed of straight lines and curves. This set is composed of vertical straight, horizontal straight, diagonal recesses, circumference and semicircles that can be seen in Fig. 2.

The circles present in each gesture represent its beginning, however, gestures were created to start at both ends, and the classifier was trained to identify the gesture starting at both ends as the same.

The lines were generated from the reduced equation of the line, represented in Equation 3. Where x and y are the points belonging to the line and c the linear coefficient.

$$y = mx + c \tag{3}$$

The work developed by the researchers of the algorithm of incremental recognition did not have curves in their templates. Considering center at the origin, defining a radius and incrementing the axis X, the axis Y can be obtained by the reduced equation of the circumference, represented in Equation 4.

$$x^2 + y^2 = r^2 \tag{4}$$

The steps to construct the base were: to recognize the participants' gestures, to store the gestures used to insert each letter, and finally to perform the Naïve Bayes classifier training, as shown in Fig. 3.

The first step, gesture recognition, is performed by the algorithm of incremental recognition, and then the gestures performed are stored and later used in the classifier training.

Fig. 4, presents an application developed in our previous work, it was used to build the base of gestures that can be used to insert a letter. Thus, based on the set of gestures of

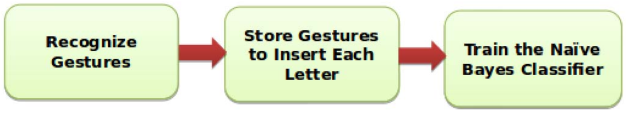

Fig. 3. Steps to build the base of gestures for insertion of letters.

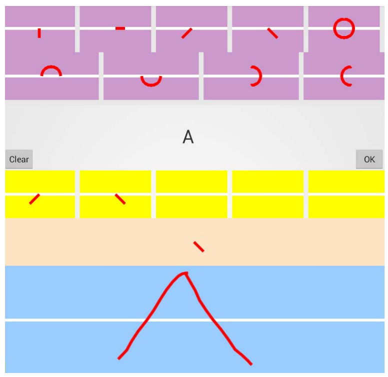

Fig. 4. Application created for the construction of the base of gestures for insertion of letters.

Fig. 2, users performed the gestures that they thought were necessary to draw a letter and repeated this process for all letters of the alphabet.

There was no limit of gestures for insertion of a letter, in this way, the user entered as many gestures as he thought necessary to draw a letter. This was used not to interfere with the classifier training, since the goal was to create a base with the most natural gestures possible that the user would use to draw a letter.

The application was used by 30 users, who performed gestures to insert each letter of the alphabet, and because each user has entered all the letters three times, each letter was inserted 90 times in total.

Users entered the letters into groups of three, in which all letters were entered once by the first user, then by the second, and finally by the third, and after that the process started again. This was done so users would not get bored and make the gestures without paying attention as well as not to induce any vice in the process.

D. Letter Recognition

For each gesture entered, the probability of all letters is calculated and, if the user enters a new gesture, a new calculation is performed. These steps can be seen in Fig. 5.

Gesture recognition is performed by the incremental recognition algorithm with the gesture template used in the training of the Naïve Bayes classifier, which is responsible for calculating the probabilities of all letters when a new gesture is performed.

Using the concepts of probability and the Bayes' theorem applied to Naive Bayes, one can calculate the probability of insertion of a letter by the formula of Equation 5.

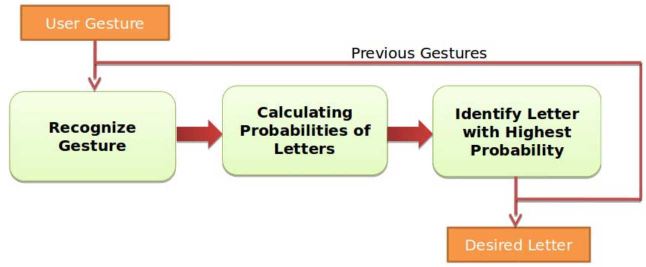

Fig. 5. Steps for letter recognition using gestures made.

Letter	Relative Frequency	Letter	Relative Frequency
E	12.702%	M	2.406%
T	9.056%	W	2.360%
A	8.167%	F	2.228%
O	7.507%	G	2.015%
I	6.966%	Y	1.974%
N	6.749%	P	1.929%
S	6.327%	B	1.492%
H	6.094%	V	0.978%
R	5.987%	K	0.772%
D	4.253%	J	0.153%
L	4.025%	X	0.150%
C	2.782%	Q	0.095%
U	2.758%	Z	0.074%

TABLE I
RELATIVE FREQUENCIES OF THE LETTERS ON THE ENGLISH LANGUAGE (ADAPTED FROM [9].)

$$P(C_k|g_1, g_2, ..., g_n) = P(C_k) \prod_{i=1}^{n} P(g_i|C_k) \quad (5)$$

Where n represents the number of gestures the user has performed.

The probability of each gesture for a letter is calculated using Equation 6.

$$P(g|C_k) = \frac{P(g)P(C_k|g)}{P(C_k)} \quad (6)$$

After performing the gestures, it is assumed that the letter with the highest probability is the one desired by the user.

E. Letter Probability

The classifier *Naïve Bayes* works with the a priori probability of an element. In this way, the probability of the letter $P(C_K)$ was calculated using the frequency of use in the English language, in this way, the most frequent letters have a higher probability a priori. The relative frequency of the letters in the English language was obtained in the book *Cryptological Mathematics* [9]. The TABLE I displays the relative frequency of use of the letters in the English language.

F. Prototype Developed

A prototype was developed that works following the steps presented in Fig. 5 and its interface can be visualized in Fig.

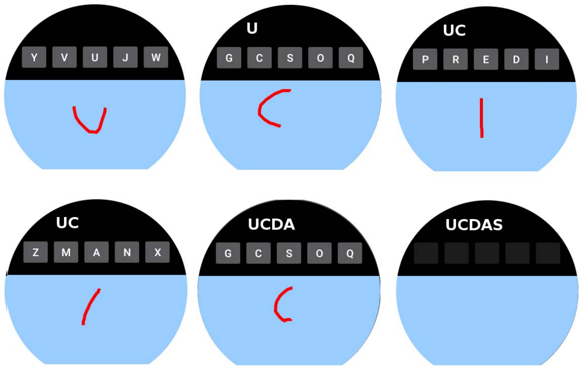

Fig. 6. Steps for insertion of the word UCDAS into the prototype developed using the *Naïve Bayes* classifier.

Interaction	More Frequent (%)	Less Frequent (%)
1	28,00%	0,00%
2	68,00%	77,78%
3	4,00%	22,22%

TABLE II
PERCENTAGE OF THE NUMBER OF INTERACTIONS USED TO INSERT THE MOST FREQUENT AND LESS FREQUENT LETTERS.

6, which presents the interface of the application and the steps for insertion of the word *UCDAS*.

This prototype uses the incremental recognition algorithm to recognize the gestures and then uses the *Naïve Bayes* classifier to identify the possible letter to be inserted.

For each gesture performed, the probability of all letters is calculated and the five letters with the highest probability of being entered are displayed, the user can select a letter or wait 2 seconds for the letter of greatest probability to be inserted.

In this context, it is possible that with at most two interactions the user can insert a letter, whether these interactions are making a gesture or choosing a letter.

IV. User Study

The experiments were conducted with 10 participants aged 21 to 48 years with a mean of 28 years. Of these, five are undergraduate students and five postgraduate students and all students in the area of computing. Only one has smartwatch. One claimed to have regular experience with smartwatches and the other nine reported having little or no experience with smartwatch. Two participants used the smartwatch in their right hand and the others in their left hand.

A goal of this work is that with at most two interactions the user can insert a letter, whether these interactions are the realization of a gesture based on the set of Fig. 2 or the choice of a letter in the options presented by the prototype .

When making a gesture the application displays the five letters most likely to be inserted, the user can select a letter or wait 2 seconds for the letter of greatest probability to be inserted.

When making a gesture and the desired letter is the most likely, it will not be necessary another user interaction, because the letter will be inserted automatically, in this way, there will be only one interaction, that of the gesture. But if the letter is not the most likely and is available in the other options, it will be two interactions, one of the gesture and another of the choice of the letter.

If the user makes a gesture and the letter is not in the provided options, he can make a second gesture, and if the desired letter is the first option, it will be inserted automatically, so there will be only two interactions as well. However, if the letter is not the most likely, there will be more than two interactions.

In order to validate the classifier and the proposed text input method, the prototype was installed on the *Motorola Moto 360 smartwatches* and *Samsung Gear Live*. An experiment was performed and participants were not offered the intention to insert a letter with up to two interactions. For this purpose was omitted, so that the participants were not influenced when entering the letters. The experiment was attended by 10 participants.

Before starting the experiment, the prototype and its functionalities were exposed to the experiment participants. The set of gestures available to be used that are shown in Fig. 2 was exposed to the participants and they could observe them throughout the experiment. For the experiments, the prototype shown in Fig. 6 was used.

In the experiment, participants entered the five most frequent letters of the English language (E, T, A, O, I) and the five less frequent letters of the English language (Z, Q, X, J, K). Each participant entered these letters three times.

The results of these experiments can be seen in the V section, which will present the results of this research.

A. Usability and Experience Test

In order to evaluate the usability and experience of the developed prototype, a questionnaire was applied to the participants of the experiments that answered usability-related assertions to verify the efficiency and effectiveness of the proposed method and questions related to the participants' experience. The affirmatives were answered by the participants using the Likert scale. The affirmations applied to the participants were:

1) The way you type text is intuitive.
2) It is easy to learn how to use the technique, that is, it was easy to enter the first few letters.
3) After the learning time (after entering some letters), it was easy and quick to enter the letters.
4) The technique has no problem in letter identification.
5) It is nice to type text using the proposed technique.
6) I would use this technique if I had a smartwatch.
7) It was nice to insert the letters using this technique.

The next section will discuss the usability and experience test results.

V. Results

The prototype was used for the validation of the proposed method and the accomplishment of a test of usability and

More Frequent		Less Frequent	
Letter	%	Letter	%
E	100,00%	Z	100,00%
T	100,00%	Q	100,00%
A	100,00%	X	100,00%
O	100,00%	J	85,71%
I	100,00%	K	90,00%
Mean	100,00%	Mean	95,14%

TABLE III
PARTICIPANTS' HIT RATE FOR THE MOST FREQUENT AND LEAST FREQUENT LETTERS.

More Frequent		Less Frequent	
Letter	%	Letter	%
E	2,0	Z	2,3
T	2,2	Q	2,0
A	1,4	X	2,1
O	1,2	J	1,9
I	2,0	K	2,0%
Mean	1,8	Mean	2,1

TABLE IV
AVERAGE INTERACTIONS USED BY PARTICIPANTS TO ENTER THE LETTERS.

experience proposed with participants. The test was designed to validate the implementation of the Naïve Bayes classifier and the proposed text input method.

It should be remembered that a specific objective of this work is to insert a letter with up to two interactions, taking into account for this reason that an interaction can be the accomplishment of a gesture or the choice of a letter in the presented options.

A TABLE II, shows the percentage of the number of interactions that participants used to insert from the most frequent and least frequent letters of the English language.

It is possible to observe that for the most frequent letters, the participants used more than two interactions in only 4% of the letters, in this way, 96% of the letters were inserted with up to two interactions. As for the less frequent letters, it is observed that the participants inserted 77.78 % of the letters using two interactions.

The participants' hit rate for entering the letters can be visualized in the TABLE III. It is possible to verify that the hit rate was 100% for all letters except the letters J and K.

However, the mean hit rate was 100% for the most frequent letters and 95.14% for the less frequent letters. These data allow us to say that the prototype is efficient in relation to the correctness of the classifications.

A TABLE IV displays the average of interactions used by participants to enter each letter. It is observed in this table that 1.8 interactions on average were used to insert a letter of the most frequent letters of the English language. It is also observed that 2.1 interactions were used on average to insert a less frequent letter. Thus, it is possible to affirm that the prototype has the potential to insert a letter using at most two interactions.

It was also possible to notice that the *Samsung Gear Live* smartwatch presented a delay to identify the letter after the gestures were done. The *Motorola Moto 360* performed better and did not show delays for letter identification.

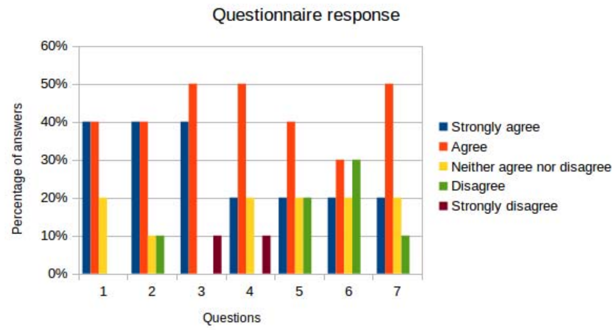

Fig. 7. Responses from the experiment participants to the applied questionnaire.

As you can see in Fig. 7 most participants marked the option I fully agree or agree to all the statements. With this, it is possible to verify that the prototype achieves its goal of perimiting text input with up to two interactions efficiently and effectively and that users have had good experience in using it.

VI. FINAL CONSIDERATIONS

The first prototypes and search results for text entry on devices with reduced touch screens have been presented in this article.

This work proposes the development of a gesture-based text entry method for devices with reduced touch screens, with the intention of inserting a letter without the user having to draw it completely and perform usability tests and method experimentation Proposed using Human Computer Interaction (IHC) standards. To do so, this work proposes to recognize gestures, identify gestures necessary to insert letters and recognize letters with up to two interactions, create an interface for smartwatches using the proposed method, elaborate and apply usability test and experience.

Using the incremental recognition algorithm, a set of gestures composed of straight lines and curves capable of being recognized by the method was created. With this set of gestures, an application was developed to collect and store the gestures that the users used to insert the letters, in this way, a base of possible gestures used to insert a letter was generated.

A prototype has been developed that allows text entry in smartwatches with up to two interactions. This prototype uses the incremental recognition algorithm to recognize the gestures and then uses the *Naïve Bayes* classifier to identify the possible letter to be inserted.

The results of the usability and experience test show that the method has the potential to allow text input into smartwatches with up to two interactions. In addition, when analyzing the usability and experience test, it is possible to verify that the developed prototype has potential to please the users, as the test result proved to be satisfactory.

It was observed during the construction phase of the classifier training base that participants had different ways of drawing a letter using the proposed gestures. In this way, it was possible to create a broader base that could serve as many people as possible.

The next step of the research will be to incorporate the prediction of words and sentences in the prototype taking into account the profile of each user, thus allowing the text entry to be more agile, efficient and personalized.

The classifier created is independent of the language, so by using the frequency of occurrence of the letters in another language, a new classifier can be created for this language. In view of this, a study of the frequency of letters in several languages will be carried out in order to be able to use the prototype developed in several countries.

Another step of the research will be to develop a method that allows text input using the user's wrist movement so that the user can enter text without touching the screen and can perform text input only by moving the arm or wrist.

VII. Acknowledgment

We would like to thank for collaboration from PixelLab members, volunteers and Instituto Federal Goiàno - Campus Iporá who were very kind and supportive on elaboration of this paper.

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