Emotion Recognition through Keystroke Dynamics on Touchscreen Keyboards

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Keywords: Human-Computer Interaction, Emotion Recognition, Keystroke Dynamics, Touchscreen, Smartphone.

Abstract: Automatic emotion recognition through computers offers a lot of advantages, as the interaction between human and computers can be improved. For example, it is possible to be responsive to anger or frustration of customers automatically while working with a webpage. Mouse cursor movements and keystroke dynamics were already used and examined for such a recognition on conventional keyboards.
The aim of this work is to investigate keystroke dynamics on touchscreen keyboards which gets a cumulative relevance through the increasingly further circulation of smartphones and tablets. Furthermore, it is possible to record additional information like pressure and size of keystrokes. This could increase the recognition rate for emotions. In order to record the keystroke dynamics, an application and keyboard layout for Android OS were developed. In addition, hypotheses were established on the basis of Yerkes-Dodson-Law and Flow theory and besides, a study with 152 test persons for the data collection was implemented. Subsequently, a data evaluation with the SPSS software was accomplished. Most of the hypotheses were confirmed and the results of the study show that emotions can be explained by the keystroke dynamics and recognized in this way.

1 INTRODUCTION

The human-computer interaction (HCI) is getting a rising relevance in the last few years because of the cumulative circulation of computers in our everyday life. Nowadays, almost everybody interacts with computers in different ways. For example the use of an elevator which is controlled by a computer or by the use of a navigation system which can be designated as a computer. One way to improve an interaction is the automatic recognition and reaction of emotions. This is relevant for the human-human interaction and the human-computer interaction. The recognition enables the automatic reaction for example to frustration and anger, which can occur during a customer process or a visit on a webpage. This improvement of working with computers can result in positive emotion which, furthermore, can increase the productivity and also the health of the working person (Cohen et al., 2003).

The subject of emotion recognition has already been examined with mouse cursor movements and keystroke dynamics on conventional keyboards. Because of the rising circulation of smartphones, tablets and general touchscreens in the last few years the aim of this work is to consider the keystroke dynamics on touchscreen keyboards for possible emotion recognition. This kind of keystroke dynamics has so far only been used for biometric authentication analysis (Buchoux and Clarke, 2008).

Within the framework of this subject an application and a special keyboard layout for the Android operating system were developed. For the theoretical background the Yerkes-Dodson-Law (Yerkes and Dodson, 1908) and the Flow theory (Csikszentmihalyi, 1975) were consulted to control the hypotheses. Subsequently, a study of 152 test persons as a data collection was implemented and an evaluation with the SPSS software was accomplished.

Section 2 will give a short theoretical background about emotion and keystroke dynamics in combination with two theories and our hypotheses. Then, we will introduce the empirical study in Section 3. In the next section we will describe the results of the study which we will discuss in Section 5 with the existing limitations and implications.

Trojahn M., Arndt F., Weinmann M. and Ortmeier F..
Emotion Recognition through Keystroke Dynamics on Touchscreen Keyboards.
DOI: 10.5220/0004415500310037
In *Proceedings of the 15th International Conference on Enterprise Information Systems* (ICEIS-2013), pages 31-37
ISBN: 978-989-8565-61-7

2 THEORETICAL BACKGROUND

2.1 Emotion, Stress, Keystroke Dynamics

Emotions are an important function of the human body to react on dangerous or extraordinary situations. Because the process of decision making of human beings is very slow, emotions can help us to respond to the current circumstances in an efficient and fast way (Maehr, 2008). Negative emotions warn us if a given aim cannot be reached and positive emotions calm down if the situation is under control. Furthermore, emotions often have a specific cause and usually are an intense experience of short duration (Zimmermann et al., 2003).

To classify the emotions, a theory with three dimensions has been developed by Mehrabian (1970), who divides all emotions into three categories (Mehrabian, 1970). The three dimensions are arousal, valence and control. The most variance exists in the first two dimensions. Therefore, the third dimension is often unnecessary and will be also not recorded in this study (Bradley and Lang, 1994).

Stress is often treated in relation with emotions (Lazarus, 2006). Stress is a synonym for pressure or tension. It describes the reaction of exterior stimuli, which enable the accomplishment of certain exercises and the resulting psychic and physical burden (Selye, 1936). These exterior stimuli can be noise, injuries, coldness or excessive demand. In general, two different types of stress exist: Eustress is the positive experienced activation of the organism and distress is the burdensome and harmful stress (Selye, 1975). Nowadays, the latter meaning is often used for stress.

Keystroke dynamics is a biometrical attribute of every human being like fingerprint, retinal scan or voice recognition (Amberg et al., 2003). Unlike a password which a person knows or an identification card which a person owns, a biometrical feature is a characteristic of a person herself (Buchoux and Clarke, 2008). The keystroke dynamics can be matched with the handwritten signature (Joyce and Gupta, 1990). In this case, the keyboard input is monitored in order to identify a pattern of tip rhythm (Monrose and Rubin, 1997). Keystroke dynamics for a touchscreen display on smartphones was already used by Trojahn et al. (Trojahn and Ortmeier, 2012). In addition to time differences, pressure and size during typing were recorded and used for authentication.

2.2 The Yerkes-Dodson-Law and the Flow-theory

The Yerkes-Dodson-Law describes the context between the productivity and the activity respectively the arousal of a person (Yerkes and Dodson, 1908). If the arousal or rather stress increases the productivity increases too. After a peak the productivity decreases. The peak depends on the respective person and the difficulty of the task. After the peak the stress is too high and the productivity decreases. The person feels negative stress. This is an example of positive and negative stress which was developed 1908 by Robert M. Yerkes and John D. Dodson.

The context between the challenge and the skills of a person is described by the Flow Theory which was invented by Mihaly Csikszentmihalyi in 1975 (Csikszentmihalyi, 1975). If the skills correspond to the current challenge of a task, a state of Flow and positive emotions come up. At this state the person is completely concentrated on his/her work and he/she does not recognize the environment around him/her. To get in this state some conditions have to be fulfilled. The goals of the task must be clear for the person and the person must have confidence in being able to fulfill the task.

2.3 Hypotheses

First of all, to study the influence of the emotions on the keystroke dynamics, hypotheses were derived from the theories. A time limit was initiated to evoke stress (Lazarus et al., 1952). According to the Yerkes-Dodson-Law the productivity rises through increasing activation or increasing stress. After exceeding a vertex, the productivity sinks again. These levels are mentioned as positive and negative stress levels.

The increased activation causes a flow state of the participants because of the increased productivity and the skills which are on this way adapted. This flow state is accompanied by positive emotions. Through further reduction of the time limit to complete the typing of the text, the stress level rises. The arise of negative emotions results from the interrupted flow state.

Stress is created by the reduction of the time limit which causes emotions. This represents the first two hypotheses.

H1: The closer the time limit, the higher the excitement.

H2: A significant difference of the valence can be observed between the groups.

The influence of the emotions on the keystroke dynamics was supposed to be examined. Former studies showed that the typing speed decreases when negative

emotions are perceived (Khanna and M.Sasikumar, 2010). Nevertheless, the error rate rises by the occurrence of negative emotions (Alepis and Virvou, 2006). The same effect can be observed at the pressure of key presses. This should also increase by the confrontation of negative emotions (Alepis and Virvou, 2006). Further hypotheses can be derived from that.

H3: The slower the typing speed, the more negatively emotions are perceived.

H4: The higher the typing error rate, the more negatively emotions are perceived.

H5: The higher the typing pressure, the more negatively emotions are perceived.

These five hypotheses were supposed to be examined within the framework of the experiment for the keystroke dynamics on touchscreen keyboards.

3 EMPIRICAL STUDY

In order to examine the keystroke dynamics an experiment was developed. Its design, the participants, the measured variables and the model specification are described in the next few sections.

3.1 Study Object and Study Task

In order to investigate the keystroke dynamics two identical Samsung Galaxy Nexus were used. The test persons were asked to enter some descriptive data like age, gender, experience and education level. After that, they were asked to enter a text which was presented to them in printed version. We tried to select a neutral text which does not cause any emotions. According to Wagner et al. (2001) we took a text about a bronze statue (Wagner et al., 2001). For the process of typing they got randomly one of three different time limits of either “no time limit”, “5 minutes” or ”3.5 minutes“. The time limits represent the different stress levels. Therefore, the time limits were calculated in a way that the task of typing the text could barely or not be mastered. After typing the text, they were asked to fill out an emotion questionnaire which was also handed to the test person in a printed version. This was created to record the emotions and the arousal which occurred during typing the text under pressure with a time limit.

We developed the software keyboard and the study application ourselves. They record the keystroke dynamics data and the descriptive data in an output file which is imported by another application into a MySQL database. By the use of export software, the data were converted and some variables were calculated to evaluate it with the SPSS software.

3.2 Study Design and Subject Participants

The design of a randomized laboratory experiment was selected. Gender, age and experience in the handling of a touchscreen can be described as random variables. The study was accomplished during the period of the 29-05-2012 to 08-07-2012. Overall, 152 test persons were consulted and the study lasted 15-20 minutes. The average age of all test persons was 31.14 years and the percentage of women was 23.68 %. We tried to get a regular distribution of the test persons over the three different time limits. Furthermore, we tried to get an equal number of male with and without experience and female with and without experience in every time limit. Figure 1 shows the distribution of the three time limits and the four different groups of persons subdivided in experience and gender.

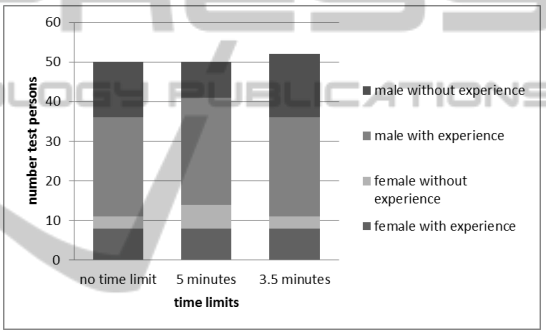

Figure 1: Distribution of the test persons subdivided into time limit, experience, and gender.

The diagram shows that almost an equal number of test persons in every time limit was reached (50 at no time limit, 50 at 5 minutes, 52 at 3.5 minutes). The number of male persons with experience is the largest. This can be traced back to the fact that most test persons are employees of an IT department or students of a technical university. The smallest part is the number of female test persons without experience.

3.3 Measure Variables

Emotion was chosen to be the dependent variable. It was recorded by the use of the emotion questionnaire, digitalized and afterwards also saved in the database. The arousal and the valence were measured and two different kinds of questionnaires (SAM and PANAS) were used. In this way the results could be compared and reviewed.

The keystroke dynamics variables were inserted as independent variables. In relation to the hypotheses the typing speed, error rate and pressure of the key presses were considered. These are calculated by

Table 1: Results of the correlation analysis.

	SAM val.	SAM ar.	speed	error rate	pressure	gender	age	time	edua. l.
SAM valence	1								
SAM arousal	0.308***	1							
speed	-0.131***	-0.020	1						
error rate	0.075***	0.056***	-0.294***	1					
pressure	-0.046***	-0.018	0.155***	0.023*	1				
gender	0.046***	-0.168***	-0.043***	-0.035***	0.122***	1			
age	0.047***	-0.281***	-0.218***	-0.019	-0.121***	0.282***	1		
time limit	0.003	0.205***	-0.008	-0.65***	0.042***	-0.002	-0.021*	1	
education level	-0.222***	-0.026**	0.003***	-0.046***	0.035***	-0.058***	-0.1***	0.071***	1

* p <0.10; ** p <0.05; *** p <0.01; 2-sided test.

the export of the data from the database into a CSV file for the evaluation with the SPSS software. All of the variables refer to single words. That means that word averages of the variables are formed for all test persons. The calculation of the typing speed is measured by the timestamp and the number of key presses of one word. The error rate describes the number of presses of the delete key. Because of this, the error rate describes the number of the conscious failure. To use the pressure an average value of all keystrokes for every word was calculated.

As control variables some different descriptive information of the test persons are applied. Age, gender, education level and the assigned time limit of the test persons were used for the evaluation. All information, except of the time limit, are entered over the application by the test persons themselves. The time limit is assigned randomly and entered by the examiner after the experiment for every study participant.

3.4 Model Specification

For the test of the hypotheses 3 to 5 we developed a linear regression model. It is shown in Formula 1 below.

$$emotions = \alpha + \beta_1 \times speed + \beta_2 \times failure\_count + \beta_3 \times pressure + controls + \varepsilon \quad (1)$$

The control variables are age, gender, education level and time limit of the test persons. In order to be able to confirm the hypotheses 3 the p-value of the β_1 must be significantly and smaller zero. For the hypotheses 4 respectively 5 the p-value of the β_2 respectively β_3 has to be significantly and greater zero.

In the evaluation four models with different numbers of control variables were defined. The first model has no control variables except of the dependent and independent variables. For the second model age and gender of the test persons are included. In the third model the time limit and in the fourth model also the education level is added. In this way the influence of the individual control variables on the model can be shown.

4 RESULTS

In the beginning of the evaluation a correlation analysis was used. Therefore, the coherences of the variables can be shown. Table 1 offers the results of the correlation analysis for all considered variables.

In Table 1 the correlation coefficients between every variable are mapped. The asterisks indicate the significance level and are therefore called significance asterisks. A high number of asterisks entail a high significance level. In the first column it can be observed that between the SAM valence variable and nearly all other variables the significance level is high. That means that a significant connection between these variables exists. Another interesting connection is between the SAM arousal and the time limit. That indicates a connection between the time limit and the caused stress.

To prove the hypotheses 1 and 2 we also implemented an ANOVA analysis for an average comparison. This calculation compares the averages and the variances between partial samples. For this study, the groups are divided into time limits. In this way, we get three different random samples. The results of the average comparison are shown in Table 2.

In the second row of Table 2 the numbers of considered objects (N) are given. The objects represent the entered words of all test persons. This number decreases by a smaller time limit because the test persons do not accomplish all words in the given time limit. It also shows that the time limit is so straightened that a complete input of the given text is not possible. In the third and fourth row the mean values and

Table 2: Results of the ANOVA analysis.

sample feature	no time limit	5 minutes	3,5 minutes	F-value
N	2158	2124	1894	
Arousal	3.630 (1.858)	4.410 (2.018)	4.660 (2.138)	147.349***
Valence	4.480 (1.656)	4.213 (1.547)	4.503 (1.843)	19.171***

* p <0.10; ** p <0.05; *** p <0.01; 2-sided test.

the variance values of the both variables in the three groups are illustrated. In consideration of the values and the F-values in the last column it is to be recognized that for the valance and the arousal variable significant differences exist between the groups. If no differences exist the F-value is nearly zero. It can be observed that the F-values of the variables are not zero and significant. That means the arousal and the valence is significantly different between the groups. In addition, we found out that the arousal rises at closer time limit. Hypotheses 1 and 2 can be confirmed with this.

The Figure 2 shows a diagram that represents the averages values of both variables over the time limits.

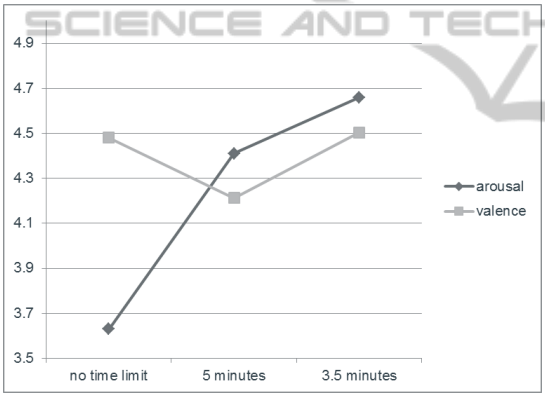

Figure 2: Diagram of the averages values of the arousal and valence variable over the three time limit groups.

By means of the diagram the differences and the rise of the arousal variable can be recognized.

In order to find the type of the connection between the variables a linear regression analysis was made. The valence is used as dependent variable which is supposed to be explained by the keystroke dynamics variables. Table 3 shows the results of the regression analysis. The four different models with the different number of control variables can be recognized.

The last row shows the number of the considered objects again. In the second, third and fourth row the keystroke dynamics variables are mapped. The control variables can be found from the fifth to the eighth row. In all four models the results of the keystroke dynamics variables are significant which is displayed by the significant asterisks. The coefficient of determination R^2 in the first three models of 2 % is relatively low. By addition of the education level variable as a control variable the coefficient rises to 7 %. The adjusted R^2 value is related to the number of variables that are observed and tries to correct the rising of the R^2 value by just adding more variables to the model. Low coefficient of determination are to be considered critically, but according to Davis (1989) (Davis, 1989) or Moon and Kim (2001) (Moon and Kim, 2001) low values in the behavior-oriented social research are absolutely common.

For the confirmation of the third hypothesis the regression coefficient of the keystroke speed needs to be significant and smaller than zero. For the hypothesis 4 the coefficient of the error rate must be significant and greater than zero. The results show that these conditions are given in all four models. Thus the hypotheses can be approved. The speed decreases and the error rate increases by the perception of negative emotions. For the last hypothesis the regression coefficient of the keystroke pressure must be significant and also greater than zero. On the basis of the results of the fourth row it is shown that the coefficient is significant in all four models but the coefficient is smaller than zero. Thus the hypothesis must be rejected.

Although the hypothesis was developed by means of the literature it could not be confirmed. Therefore, this topic will require further research in future studies.

5 CONCLUSIONS

5.1 Summary

Through the evaluation of the collected data with the SPSS software most of the developed hypotheses could be approved. Stress and emotions can be caused by the commitment of time limits. These evoked emotions can be explained by the keystroke dynamics variables keystroke speed and error rate. Thus, the first four hypotheses could be confirmed. The keystroke pressure becomes significant smaller by the perception of negative emotions. Therefore, the last hypothesis has to be rejected and more studies are required in order to keep on examining this phenomenon.

Table 3: Results of the regression analysis.

	-1	-2	-3	-4
keystroke speed	-0.106***	-0.102***	-0.102***	-0.111***
failure count	0.061***	0.066***	0.067***	0.047**
keystroke pressure	-0.545**	-0.642***	-0.648***	-0.448*
gender		0.181***	0.182***	0.169***
age		0.001	0.001	-0.003
time limit			0.013	0.052**
education level				-0.285***
constant	4.982	4.848	4.837	5.523
R^2	0.019	0.022	0.022	0.070
adjusted R^2	0.019	0.021	0.021	0.069
N	6221	6221	6221	6221

* p <0.10; ** p <0.05; *** p <0.01; 1-sided test.

5.2 Limitations

Like in every other study some limitations occur in this study which is supposed to be named and explained in the following. First of all, it must be explained that the effect of the exercise itself cannot be controlled because only one exercise was considered. Furthermore, the study was implemented in a controlled setting. This means that not all exterior influences were regarded. It is possible that the test persons had already negative emotions or were stressed before the experiment started. This might have distorted the results of the study, respectively the recorded data of the emotion questionnaire. Furthermore, the influence of the hardware setting should be named. The study was implemented with a smartphone with and Android operation system. Test persons who have already used an Android smartphone before have more experience in the handling which could also distort the results in this way. Through the development of a self-constructed keyboard this effect should be avoided. Nevertheless, this cannot be completely assured.

The small percentage of female participants and the unevenly distribution of the education level are further limitations of the study. Also the rate of the persons who accomplished the complete text within the 3.5 minutes can have an influence on the results. Because they reached the aim for entering the text in the pre-set time limit, they were most probably stressed, but in a positive way. At the closest time limit it was planned that negative emotions are caused by non-attaining. However, the part of the persons who managed it in spite of the close time limit was only near 29 %.

Moreover, also the small coefficient of determination must be named as a limitation. As already mentioned, small values are normal in the behavior-oriented social research (Davis, 1989; Moon and Kim, 2001). Nevertheless, there should be more research into this topic in future studies. In addition, the results for the control variables should be mentioned. The regression coefficients for example of the gender variable are significant in all four models. This implies that it has a significant influence on the dependent variable and would have to be considered, therefore, actually as an independent variable.

With respect to a commercial use even the data privacy has to be considered. The self-developed software is in principle a key logger which can be used to save passwords or other sensitive information. Solutions for that must be clarified in the case of an introduction. An option would be to recognize automatically the input of passwords and to stop the saving for this input.

Last but not least we should refer to the not confirmed hypothesis of the keystroke pressure. By the feeling of negative emotions the pressure is smaller, not greater. This cannot be occupied by means of the currently literature, so more studies are required in this section. Because the pressure can be recorded on conventional keyboards exclusively with supplementary hardware, the number of studies is up to now small in this range. In the coming years this will probably change because through the increasingly further circulation of touchscreens a lot of new possibilities will occur.

5.3 Implications

The study and the results show that the described Yerkes-Dodson-Law and the Flow theory could be validated. The evaluation proves that positive stress exists and that it can be initiated. Furthermore, the productivity increases by the perception of positive stress. This represents important results for the behavior and stress research in the work environment.

The main intention of this study, to investigate the automatic recognition of emotions through keystroke dynamics on touchscreen-keyboards, was processed

and successfully completed. Emotions can be explained by the keystroke dynamics. This opens new possibilities for marketing departments and interface designers who can deal with customers purposefully. With the aid of these findings it is possible to develop systems which give supports automatically in the case of recognition of e.g. frustration. In the e-commerce environment this can be enormously helpful and represent a competitive advantage.

Also in the domain of the authentication with the use of the keystroke dynamics the results should find attention because it was shown that the keystroke dynamics is strongly influenced by emotions. This influence must be considered in relation to the development of the algorithm and during the training of the algorithm for an authentication.

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