EFFECT OF SIMULTANEOUS AND SEQUENTIAL USE OF KEYS ON THE CORRECTNESS OF ENTERING COMMAND STRINGS INTO DEVICES

Analiza wpływu równoległego i sekwencyjnego wykorzystania przycisków na poprawność wprowadzania ciągów poleceń do urządzeń

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A b s t r a c t: Controlling the operation of many devices (e.g. machine tools or assembly lines) requires that proper communication is ensured between man and the machine for the purpose of entering appropriate instructions that will control the machine operation. To this end, control panels, among other things, are used to enable the operator to control the device. Such panel may have many various forms; very often they are computer keyboards. The problem of correct entering appropriate instructions at the right moment by the operator certainly has an impact on the quality of the final product. Should the operator make a mistake, the product will not meet the desired requirements. It becomes necessary to design keyboards used as control panels in which the arrangement of characters would facilitate correct entering of instructions. One of the main issues is to define the most effective way, simultaneous or sequential, of using key while entering instructions from the control panel. The study presented in the paper describes the effect of using a combination of keys (i.e. simultaneous use of more than one key in order to enter a signal) in controlling a machine on the correctness of the signals being entered. The results presented were compared with using only the sequential pressing of keys. The study presented in the paper was conducted using a computer keyboard.

S t r e s z c z e n i e: Sterowanie działaniem wielu urządzeń (np. obrabiarek, zespołów montażowych) wymaga zapewnienia komunikacji człowieka z maszyną, w celu wprowadzenia do urządzenia odpowiednich instrukcji, które sterować będą działaniem maszyny. W tym celu wykorzystywane są m.in. panele sterownicze, poprzez które operator ma możliwość sterowania urządzeniem. Panele te mogą przyjmować najróżniejsze formy, bardzo często są to klawiatury komputerowe. Problem poprawnego wprowadzania przez operatora odpowiednich instrukcji w odpowiednim momencie ma niewątpliwy wpływ na jakość wytworzonego produktu końcowego. W przypadku popełnienia przez operatora błędu produkt nie będzie spełniać żądanych wymagań. Konieczne staje się projektowanie klawiatur – paneli sterowniczych, w których rozmieszczenie znaków ułatwiałoby prawidłowe wprowadzanie instrukcji. Jednym z głównych zagadnień jest określenie najefektywniejszego sposobu – równoległego lub sekwencyjnego – wykorzystywania przycisków przy wprowadzaniu poleceń z panelu sterującego. Zaprezentowane w artykule badania przedstawiają wpływ wykorzystania w sterowaniu maszyną kombinacji klawiszy (jednoczesnym użyciu więcej niż jednego klawisza w celu wprowadzenia danego sygnału) na poprawność wprowadzanych sygnałów. Przedstawione wyniki zostały porównane z rezultatami przy wykorzystaniu jedynie sekwencyjnego wykorzystania klawiszy. Prezentowane w artykule badania zostały przeprowadzone z wykorzystaniem klawiatury komputerowej.

Introduction

The problem of correct entering control signals into machines is present in all activities during which a person interacts with a machine. Due to the continually increasing level of automation and robotisation [2] of, inter alia, manufacturing operations, this problem seems topical and, taking into consideration the efforts made by companies to ensure a high quality of their products [3, 4], it can also be perceived as essential. In this paper, the authors focused on an analysis of the effect of one of the many factors that may affect the correctness of the signals being entered, i.e. on the effect of entering signals by simultaneous and sequential pressing of keys.

The problem concerned occurs, inter alia, in the case of control panels on which it was impossible, e.g. due to the limited space, to place a separate key for each signal that can be entered. For this reason, some of the signals can be generated by pressing a number of keys in the right sequence or by pressing at least two keys at the same time. The analysis of the effect of the particular solution (sequential and simultaneous pressing of keys in order to generate a signal) on the correctness of the signals being entered is the key element of the considerations further on in the paper.

This study does not concern situations in which simultaneous pressing of more than one button in order to generate a signal is required e.g. for safety reasons. Such safety measures are used in order to protect the person operating the machine e.g. by forcing them to press buttons with both hand so that neither hand is exposed to risk of injury as a result of the machine operation.

The data necessary for conducting the analysis of the problem were collected by the authors through an empirical study the conclusions from which (as well as a detailed description of the study) have been presented further below.

Description of the study

The purpose of the empirical study was to collect empirical data concerning the correctness of entering predetermined sequences of characters. In the tests, PC computers were used, equipped with keyboards compliant with ISO/IEC 9995-2 [ISO/IEC 9995-2:2009]. The authors decided to collect data based on entering characters using a computer keyboard for among others the following reasons:

- computer keyboards (or their versions modified to suit a particular device) are used to control different machines (e.g. CNC machine tools) and their application can be extended to include many other types of devices;
- collecting a sufficient amount of representative data to conduct reliable analyses;
- conducting the study using keyboards will make it possible to collect data from a large number of users who work with a keyboard on a daily basis and therefore the aspect of unfamiliarity with the key arrangement (machine control interface) is negligible.

Data for further analyses were collected by conducting an experiment which was divided into two parts:

1) A survey.
2) A test in which users had to type in a specially selected text.

The first part of the experiment was a survey. During the survey, basic information about the study participants was collected, such as age, gender and field of study. In the second part of the experiment participants were given four texts which they then had to copy. During this part of the study the data that were collected concerned the signal sequences entered by each user (by pressing a key or a combination of keys) as well as the exact time taken to generate each signal.

The second part of the study was divided into four sections each of which contained a different text to be copied. In the literature there are many different approaches to the issue of selecting contents in this type of studies. In papers [1] and [6] the contents of the experiment were all possible two-letter combinations. The study [5] used extracts from the books describing Alice's Adventures in Wonderland. In studies [Karat et al. 1999] one of the passages used was from a book on the Wild West. The content of the study [Norman, Fischer, 1992] was an article from a magazine while in [Lee, Zhai, 2004] the authors created a base containing two hundred twelve-word sentences from newspapers.

In order to conduct the study, the authors decided to develop their own method of creating the study text. The part of the study in question was divided into four parts; each of the elements contained one section of texts. Texts comprising each section were selected according to the following criteria:

- section one comprised extracts from Pan Tadeusz [Sir Thaddeus] by Adam Mickiewicz and The Lord of the Rings by John Ronald Reuel Tolkien;
- section two was compiled in a way that forced alternate typing based on the assignment of each key to a particular finger [8];
- in section three, the change of hand used for typing takes place exactly every two keystrokes;
- the last section, unlike the other ones, contains also digits in addition to text content.

All the sections were divided into separate sequences (the next section began at the next character relative the character finishing the previous sequence) with a length of two to five keystrokes.

The test was performed on a sample of 365 participants. All apart from four participants were full-time first-cycle students at the Faculty of Management of the AGH University of Science and Technology in Krakow. The most numerous group among the participants were students of Information Technology and Econometrics who were 183. There were slightly fewer (175) students of Management. The breakdown of the participants according to gender shows almost equal shares of women and men in the study, with a slight prevalence of men (195 to 170). Figure 1 presents breakdown of users with regard to the declared number of fingers used in typing (apart from the thumbs). By far the most numerous were the participants who used all fingers (8) for typing or six fingers.

Due to small numbers of participants in some of the intervals the authors decided to divide the study

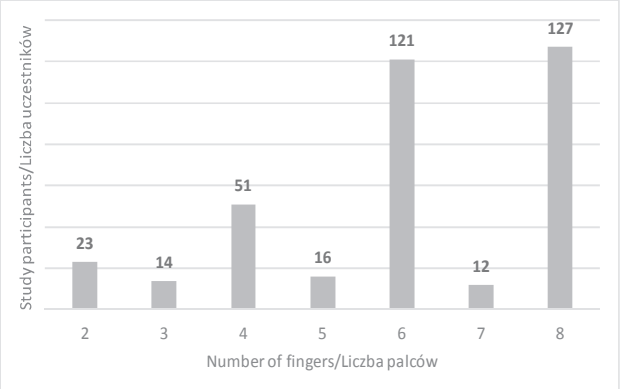

Fig. 1. Breakdown of study participants by the number of fingers used for typing.
Source: own study
Rys. 1. Podział uczestników badania ze względu na liczbę palców wykorzystywanych do pisania.
Źródło: Opracowanie własne

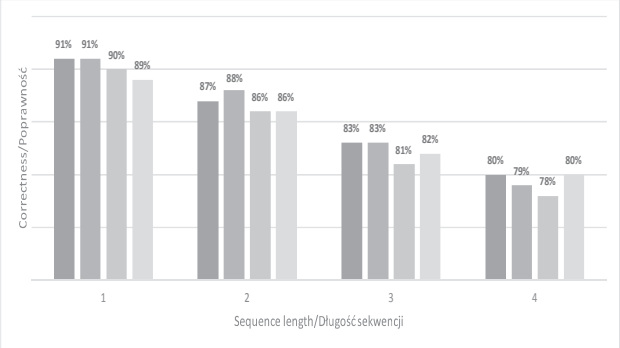

Fig. 2. Average level of correctness depending on the sequence length.
Source: own study
Rys. 2. Podział uczestników badania ze względu na liczbę palców wykorzystywanych do pisania.
Źródło: Opracowanie własne

participants into 3 groups with regard to the number of fingers used for typing:

1) People who type with two, three or four fingers (hereinafter group 2-4).
2) People who type with five or six fingers (hereinafter group 5-6).
3) People who type with seven or eight fingers (hereinafter group 7-8).

The analysis of the results obtained based on the test described above is the next part of this paper.

Analysis of results

The results obtained based on the experiment described in the previous part of the paper were analysed in terms of the effect of the section of the experiment, the number of fingers used and the length of the sequence on the correctness of entering the sequence. For the purpose of the study, a correctly entered sequence should be understood as the occurrence of an error-free n-element sequence (n subsequent elements of the sequence must be identical with the characters making up the n-element sequence) in the sequence of characters entered by the user. The correctness rate for a single participant denotes the quotient of the number of correctly entered sequences and the total number of sequences (with a matching length) in a particular section. Sequences with lengths of two to five characters were analysed in the study. Figure 2 presents the average levels of correctness for each section (1-4) depending on the length of the sequence (2-5).

Based on the chart shown it can be concluded that along with the increase in the length of the sequence the rate of correctness of entering the sequence decreases. This correlation seems intuitive and is corroborated in the data presented.

Due to the differences in the rate of correctness between the sections, further analyses will take account of the breakdown of the data into the individual sections.

Table 1 presents the correctness rate for different lengths of sequences taking into account the section of the study and the number of fingers used by the participants for typing in the characters. Based on the data contained it can be concluded that sequences are most accurately (with the highest correctness rate) entered by participants using five or six fingers for typing. The level of correctness for participants typing with all (or almost all) fingers begins to clearly depart from the results of the aforementioned group together with the increase in the length of the sequence. Attention should, however, be paid here to the other part of the table containing the average time taken to enter a single signal (calculated as the time taken to enter a sequence divided by the length of the sequence). The average times in the group of participants using the largest number of fingers are significantly lower than in the other groups. Based on this it can be concluded that an increase in the speed of typing increases the probability of making an error in the process (which conclusion also confirms the intuitive expectations).

The average time taken to enter one character for a particular number of fingers is comparable for the sequence with a length of three to five characters.

In order to compare the results for simultaneous and sequential entering of signals, the following interpretations were assumed for each of the types of entering signals:

– signals entered simultaneously in the study will be understood as entering an accented character (requiring simultaneous pressing of the AltGr key and the key for a particular character), upper-case letters (which require pressing the Shift key in combination with a particular character) as well as characters the must be entered using the Shift key;
– sequential signals will be understood as entering any two letters of characters that will be treated as one signal for the purpose of this study.

These interpretations serve to determine the attribute the number of signals. In this study the authors limited the number of signals entered simultaneously or sequentially that will belong to the mentioned sequences of characters to exactly one. Therefore, the number of signals will mean:

– for simultaneous signals – the length of the sequence containing exactly one character that requires simultaneous pressing of the AltGr or Shift key (but not both of them at the same time) and another key for the particular character;

Section no	Number of fingers												
	2-4	5-6	7-8	2-4	5-6	7-8	2-4	5-6	7-8	2-4	5-6	7-8	
1	91%	92%	91%	88%	88%	87%	83%	84%	82%	80%	80%	79%	Correctness
2	91%	92%	91%	88%	88%	87%	84%	84%	82%	80%	80%	77%	
3	91%	91%	88%	86%	88%	83%	82%	83%	79%	79%	80%	75%	
4	86%	91%	89%	84%	88%	85%	81%	85%	81%	78%	82%	78%	
1	318	302	270	323	308	271	322	309	270	322	310	270	Average time of typing one number
2	468	435	391	473	444	398	478	452	399	477	452	40	
3	442	394	354	449	399	358	453	401	360	451	401	358	
4	525	480	459	534	490	471	542	497	474	543	498	474	
	2			3			4			5			
	Sequence length												

Table 1. Correctness and average time of typing depending on the number of fingers used for typing, text selection, text section and the length of sequence
Tabela 1. Zestawienie poprawności i średniego czasu pisania w zależności od liczby wykorzystywanych do pisania palców, sekcji tekstu badania oraz długości sekwencji

Section no	Number of fingers									
	2-4	5-6	7-8	2-4	5-6	7-8	2-4	5-6	7-8	
1	91%	92%	90%	87%	87%	85%	85%	85%	83%	Sequential
2	90%	90%	89%	87%	88%	85%	84%	84%	80%	
3	88%	90%	86%	84%	86%	82%	81%	83%	79%	
4	86%	90%	88%	82%	86%	83%	80%	84%	80%	
1	86%	87%	86%	79%	79%	78%	78%	78%	78%	Simultaneous
2	89%	90%	89%	86%	86%	84%	82%	82%	80%	
3	88%	88%	84%	84%	85%	80%	81%	81%	77%	
4	82%	87%	83%	77%	82%	77%	78%	83%	78%	
	2			3			4			
	Number of signals									

Table 2 presents average levels of correctness depending on the section number and the number of signals.
Table 2. Correctness of entering sequences of signals where one of the signals in the sequence requires two sequential or simultaneous keystrokes
Source: own study

– for sequential signals – the length of the sequence less one (two characters in the sequence will generate one signal).

For all the cases shown in Table 2, sequential entering gives results not worse than for simultaneous entering. On this basis it can be stated that if there is no possibility to have separate buttons for each control signal on the machine control panel, it is more advantageous to generate signals sequentially than simultaneously.

Figure 3 presents a chart of the correctness rate for a given number of signals taking into account the number of fingers used for typing.

The chart demonstrates that entering signals by forcing simultaneous use of more than one key gives significantly worse results than entering signals using a sequence of keys. The differences in the level of correctness vary between 2.5 and 4 percentage points in favour of the sequential entering of characters.

Summary

The authors undertook to investigate the effect of the simultaneous and sequential entering of signals on the correctness of the sequence of signals being entered. For this purpose, an experiment was designed which enabled collecting necessary data in order to conduct analyses relevant to the participant matter. It should be remarked that the problem considered by the authors only concerns such devices for which it is necessary to enter selected signals by using simultaneous or sequential pressing of keys.

The analysis demonstrated that it is more advantageous to used rather sequential than simultaneous entering of signals. These results were obtained for each

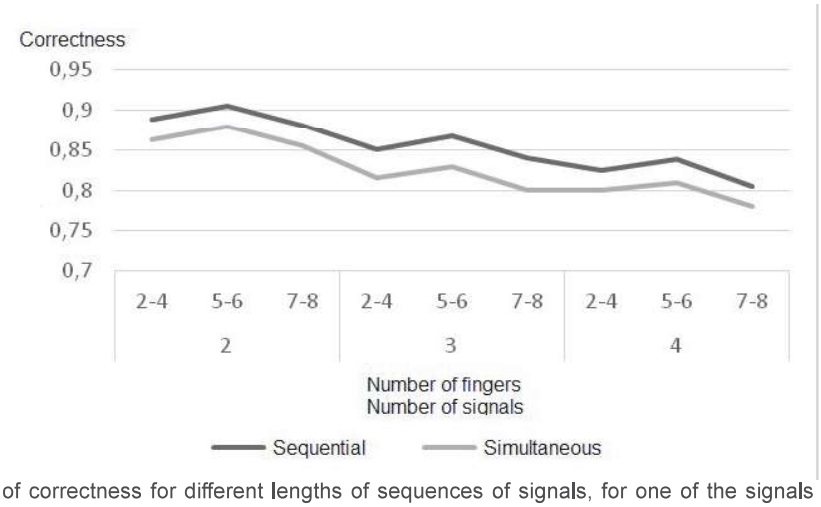

Fig. 3. Average level of correctness for different lengths of sequences of signals, for one of the signals entered sequentially and simultaneously
Source: own study
Rys. 3. Średni poziom poprawności dla różnej długości sekwencji sygnałów, dla jednego z sygnałów wprowadzanego sekwencyjnie oraz równolegle.
Źródło: Opracowanie własne

of the analysed lengths of sequences and regardless of the number of fingers used for typing.

In further studies the authors intend to design a keyboard that will meet the stipulated requirements. For this purpose, the authors will take advantage of the 'dead key' functionality to enable modification of the signal generated by the key pressed immediately after a dead key. This solution will allow to reduce the number of signals that must be generated by simultaneous pressing of at least two keys.

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