Algorithm for Predicting the Speed of Gesture Interaction with the User Interface of a Mobile Software Application

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Abstract. In this article, Keystroke Level Model and Touchless Hand Gesture Level Model were adapted, as well as Fitts's law, to work with touch screens of the mobile devices. The article takes into account typical gestures that users most often perform in the process of interaction with touch screens of mobile devices (Tap, Pinch, Swipe, Pan, Drag-and-Drop), as well as time components of gestures (time for direct execution of a gesture, time for mental preparation for the gesture, time for the user to select the necessary grip on the mobile device, time to select the ‘dominant’ hand to perform gestures, the time to select the finger to perform the gesture, time to move the hand away from the touch screen). A method for determining the speed of user gesture interaction has been developed. The problem was formulated and an algorithm was developed. The details of the operation and use of the algorithm are considered. A list of arrays and variables used as initial data for determining the speed of the sequence execution of operations using gesture interaction has been developed. The preparation of the initial data for the operation of the algorithm provides for a research experiment to obtain average values of the temporal components of gestures. The developed algorithm is intended for use at the design stage of mobile software applications that will run on mobile devices with touch screens.

1. Introduction

Most mobile devices are equipped with touch screens that support user interaction with touch screens using fingers to enter data. The features of gesture interaction with user interfaces differ from the features of interaction with user interfaces using a mouse and keyboard. With gesture interaction, the user interface controls respond to the interaction in accordance with the gestures that the user uses. According to [1], a gesture is a movement of the fingers containing information.

In this paper, physical interactions of the user with the touch screen of the mobile device (using one finger) while working with the user interface of a mobile software application are considered as gestures.

2. Relevance and task statement

To assess the speed of work with the user interfaces, various models of user interaction with software applications are used. Speed estimation models can be descriptive or predictive. In [2, 3], models are given that can be used to predict the speed of work with the user interface, as well as to form models of user interaction with software applications. Also in [4] several models are given that can be used as
a theoretical basis for creating new models. MHP (Model Human Processor) and GOMS (Goals, Operators, Methods and Selection Rules) can be considered as such models. The MHP model [4] assumes that the human mind is an information processing system described by perceptual, cognitive and motor processors, working and long-term memory, and principles of work. The GOMS methodology brings together a family of models. One of such of these models is the KLM (Keystroke Level Model) for predicting the user working time with a software application [2, 4]. At the same time, time of execution of work with the user interface is considered in [5] as a performance indicator. The KLM model predicts the time it takes to complete a task for users to interact with computers using keystrokes on the keyboard. In addition, the KLM model is often used to analyze other styles of interaction with user interfaces of software applications running on mobile phones [6], mobile devices [7] and using touch screens [8]. At the same time, both the KLM model and its variants do not provide possibilities of user interaction with the software application, which are available in the THGLM (Touchless Hand Gesture Level Model) model [9]. The gestures used to manipulate the user interface according to the THGLM method are more complex than the keyboard and mouse manipulations according to the KLM method. Therefore, the set of operators used to determine working time with user interface in accordance with the THGLM methodology, is different from the operators, used in the KLM methodology. Within the THGLM model [10, 11], framework, the terms ‘gesture units’ (G-units) and ‘gesture phrases’ (G-phrases) are considered for the gestural interaction research. In this article, given terms correspond to the terms G-operation and G-action. Therefore, in analogue with [11], a G-operation consists of one or several G-actions, which duration is analyzed taking into account their structure. In accordance with [12], the G-operation begins with the movement of the arms from the state of rest and ends with the return of the arms to the state of rest. Each of the G-actions included in the G-operation consists of one or more phases. The first and optional phase of the G-action is preparation (the hand and is moved from the resting position to the position at which the gesture begins). The second and obligatory phase is the actual execution of the gesture [9, 10]. The composition of gestures in accordance with [10, 11, 14] may include an optional retention phase. This phase can precede or follow a gesture [10, 13, 14]. It should be taken into account that gestures, considered in the THGLM model [11], only partially correspond to the gestures currently used when working with mobile devices with touch screens. Fitts's law is often used to calculate the time it takes to select controls on the user interface using a mouse [15]. An example of such an application of Fitts's law is given in [16]. The use of Fitts's law to research user interaction with a touch screen is given in [17]. At the same time, it was established in [17] that Fitts's law can be used to analyze the time spent working with user interfaces of interfaces based on the THGLM model, but its use is limited only to the tasks of pointing to controls. Thus, adaptation of the THGLM and KLM models, as well as Fitts' law to interaction with touch screens of mobile devices, will allow predicting the speed of work with user interfaces of software applications launched on mobile devices with touch screens. As a parameter, characterizing productivity of the user, time taken by the user to execute a set of G-actions on the user interface of the mobile software application, when performing the required G-operation, is considered. The execution time of the G-operation is equal to sum of execution times of all G-actions included in the G-operation, taking into account preparation time for the operation and time when the hand is removed from the touch screen. The number of G-actions in a G-operation depends on complexity of the G-operation and design of the user interface. To interact with touch screens of mobile devices in accordance with [18, 19, 20], this article considers the gestures ‘Tap’ (gesture execution time is equal to $\Delta t_{\text{Tap}}$), ‘Pinch’ (gesture execution time is equal to $\Delta t_{\text{Pinch}}$), ‘Pan’ (gesture execution time is $\Delta t_{\text{Pan}}$), ‘Swipe’ (gesture execution time is $\Delta t_{\text{Swipe}}$), ‘Drag-and-Drop’ (gesture execution time is $\Delta t_{\text{Drag-Drop}}$). The execution time of i-th G-action is determined, taking into account the time $\Delta t(i)_{\text{GFP}}$ of the preparation phase for its execution.

The preparation phase time consists of the following time intervals [2]: time interval $\Delta t_{\text{MP}}$ for mental preparation for performing the G-action, time interval $\Delta t_{\text{CDC}}$ for the user to select the type of holding the mobile device, time interval $\Delta t_{\text{PF}}$ for the user to select the hand preferred to perform G-action, time interval $\Delta t_{\text{PF}}$ for the user to select the finger with which the G-action will be performed.
When designing the user interface of the mobile application, the following types of holding the mobile device should be taken into account: holding a mobile device with one hand, holding a mobile device with two hands, a mobile device at a distance that is less than the length of an outstretched arm, a mobile device at a distance that is greater than arm length. When choosing a preferred hand for performing a gesture, it should be taken into account that in case of a hand, that is ‘dominant’ for a user, according to [21], users spend 11 per cent less time preparing for the gesture.

Problem research statement:

**Given:**
- Array $LU$, showing the user experience level (users with no experience with touch screens, users with insufficient experience with touch screens, experienced users): 
  
  $$LU = \{lu(u); u=1, 2, 3\} = \{\text{nex}, \text{nenex}, \text{ex}\}.$$  

- Array $OP$, containing the sequence of the G-operations: 
  
  $$OP = \{op(f); f=1, 2, \ldots F\}.$$  

- Array $GST$, containing the names of the typical gestures (‘Tap', 'Pinch', 'Swipe', 'Pan', 'Drag-and-Drop'), which can be used to perform the G-operations from the array $OP$. 
  
  $$GST = \{gst(k); k=1, 2, \ldots 5\}.$$ 

- Array $T$, containing the time of the gestures performance $t_{\text{tap}}, t_{\text{ps}}, t_{\text{pan}}, t_{\text{swipe}}, t_{\text{dd}}$: 
  
  $$T = \{t(k); k=1, 2, \ldots 5\}.$$ 

- Array $LG$, containing the set of degrees of user mental readiness to perform $i$-th $G$-action in accordance with the gradation, given in [2, 11]:  
  
  $$LG = \{lg(j); j=1, 2, \ldots , 6\} = \{MS', MR', MN', ML', MC', MV\}.$$ 

In accordance with [2, 11]:

- ‘MS’ – simple user reaction (user exactly knows how to work with the user interface and reacts unambiguously when a stimulus appears to perform the $G$-action).
- ‘MR’ – performing a physical comparison (a user who, when a stimulus appears to perform a $G$-action, understands how to perform a $G$-action and has several options for its implementation in his short-term memory).
- ‘MN’ – performing matching of action names (user, upon receiving a stimulus to perform a $G$-action, does not understand what is need to be done and must first figure out, what is need to be done to perform the $G$-action).
- ‘ML’ – performing a comparison of classes of actions (user, upon receiving a stimulus to perform the $G$-action, understands what is need to be done, and must first figure out what is need to be done to perform the $G$-action).
- ‘MC’ – user, upon receiving a stimulus to perform a $G$-action, understands how and with what controls on the user interface he must work (in accordance with Hick’s law [22]).
- ‘MV’ - when a user receives a stimulus to perform the $G$-action, understands how and with which control on the user interface he should work and how to select it (in accordance with Fitts’s law [15]).

Array $MP$, containing the initial data on user’s mental preparation time for performing $i$-th $G$-action:  

$$MP = \{mp(j); j=1, 2, \ldots , 6\};$$

$$mp(1) = \Delta MP_{\text{MS}}, mp(2) = \Delta MP_{\text{MR}}, mp(3) = \Delta MP_{\text{MN}};$$

$$mp(4) = \Delta MP_{\text{ML}}, mp(5) = \Delta MP_{\text{MC}}, mp(6) = \Delta MP_{\text{MV}}.$$ 

Array $MNT$, containing initial data for determining preparation time for execution of $i$-th $G$-action:  

$$MNT = \{mnt(l); l=1, 2, 3, 4\}, \text{ where } mnt(1) = \Delta MP; mnt(2) = \Delta PP; mnt(3) = \Delta MDC; mnt(4) = \Delta PF.$$ 

Array $H$, containing the time to prepare for the gesture, time to move the arm after the gesture, and the response time of the software application to the gesture ($\Delta _{Pr}, \Delta _{Re}, \Delta _{Re}$):  

$$H = \{h(z); z=1, 2, 3\} = \{\Delta _{Pr}, \Delta _{Re}, \Delta _{Re}\}.$$ 

User experience level $il$. 


The maximum value of the time interval $\Delta_{\text{MAX}}$, between the performed and next $G$-action, at which there is no need to remove the hand.

**Required:**
Form the $\text{ALG}$ transformation in the form of the algorithm that allows using the initial data to determine the execution time of the $\text{TOP}$ sequence of $G$-operations:

$$\text{ALG}: \{ \text{LU, OP, GST, T, LG, MP, MNT, HB} \} \rightarrow \text{TOP}. $$

3. **Methodology for predicting the speed of gesture interaction**
Each of the $G$-operations, included in the $\text{OP}$ array, can consist of one or more $G$-actions (gestures). Moreover, each $G$-action consists of one or more phases. The preparation phase consists in moving the user’s hand from the rest state (from the initial position) to the state corresponding to the execution of the first gesture that is part of the $G$-operation. The preparation phase is characterized by a time interval $\Delta_{\text{P}}$. This period of time is used every time the user needs to physically prepare his hand for the first gesture. A gesture ($G$-phrase) matches one of the gestures contained in the $\text{GST}$ array. The phase of removing the hand to rest (to the initial position) begins at the moment when the user has performed the last gesture ($G$-action), which is part of the $G$-operation, and is characterized by the time interval $\Delta_{\text{R}}$. If the $G$-action includes several $G$-actions, then the phase of removing the hand after the execution of the $G$-action is performed only if the time interval $\Delta_{\text{pause}}$ (between the performed and the next $G$-action) exceeds the time interval $\Delta_{\text{MAX}}$. In this case, the time interval $\Delta_{\text{P}}$ must also be taken into account before starting the next phrase.

In [11], for the execution time of the $G$-operation, the following ratio is valid:

$$T_{\text{GDP}} = \Delta t_{\text{P}} + \sum_{i=1}^{I} T(i)_{\text{G}} + \Delta t_{\text{R}}.$$

where $I$ – number of $G$-actions, included in $G$-operation;
$T(i)_{\text{G}}$ – time is taken to perform the $i$-th gesture.

Each of $f$-th $G$-operation (element of the $\text{OP}$ array) corresponds to the array $\text{KE}$, which displays the composition of a cognitive unit (sequence of $I$ $G$-actions, required to perform the $f$-th $G$-operation):

$$\text{KE} = \{ ke(i); i=1, 2, \ldots, I \} = \{(G\text{-action})_1, (G\text{-action})_2, \ldots, (G\text{-action})_I \}.$$

Each element $ke(i)$ corresponds to an element $tl(i)$ of the $\text{TL}$ array, in which the execution time of the $i$-th $G$-action is written.

The execution time of the $i$-th $G$-action is determined by adding the time $\Delta t(i)_{\text{G}}$ of preparation for the execution of the $i$-th $G$-action, which consists of the time intervals $\Delta t_{\text{MP}}, \Delta t_{\text{MPV}}, \Delta t_{\text{PF}}$.

After $i$-th $G$-action is completed, the response time $\Delta_{\text{RT}}$ of the software application to the gesture is taken into account. The response time is taken into account only when, without evaluating the results of the performed $i$-th $G$-action, the next $G$-action cannot be performed. The time interval $\Delta t_{\text{MP}}$ of the user’s mental preparation for $i$-th $G$-action is taken into account by choosing one of the $\text{MP}$ array elements corresponding to one of the user experience level (‘MS’, ‘MR’, ‘MN’, ‘ML’, ‘MC’, ‘MV’):

$$\Delta t_{\text{MP}} = \Delta t_{\text{MPS}} | \Delta t_{\text{MPV}} | \Delta t_{\text{MPS}} | \Delta t_{\text{MPV}} | \Delta t_{\text{MPV}} | \Delta t_{\text{MPV}}.$$

The user experience level $il$ is taken into account as follows:

- For non-touchscreen users ($il$ is ‘nex’), consider the amount of time to mentally prepare before performing each $G$-action, and also consider the response time of the software application.
- For users with little experience with touch screens ($il$ is equal to ‘nenex’), consider the amount of time for mental preparation before each cognitive $\text{KE}$ unit, as well as take into account the response time of the software application after the end of the cognitive unit.
- For users with extensive experience ($il$ is equal to ‘ex’), often the time interval for performing the next $G$-action and the time for receiving a response from the software application after performing this $G$-action are combined with the time interval for mentally preparing for the
next $G$-actions. In this case, the gap for mental preparation can be partially or completely absorbed by other periods of time:

$$\Delta t(i)_{MP}^{user} = \begin{cases} 0, & \text{if } (\Delta t(i)_{\text{Exec}} + \Delta t_{RT}) \geq \Delta t_{MP} \\ \Delta t_{MP} - (\Delta t(i)_{\text{Exec}} + \Delta t_{RT}), & \text{if } (\Delta t(i)_{\text{Exec}} + \Delta t_{RT}) < \Delta t_{MP} \end{cases}$$

where $\Delta t(i)_{\text{Exec}}$ is the time interval spent directly on the execution of the $i$-th $G$-action and corresponding to an element of the $T$ array and a gesture from the GST array.

In this case, for the first two cases (the value of $il$ is equal to ‘nex’ or ‘nenex’), before performing the first $G$-action, the following ratio is performed:

$$\Delta t(i)_{MP}^{user} = \Delta t_{MP}.$$ 

As a result, the preparation time for $i$-th $G$-action is:

$$\Delta t(i)_G = \Delta t(i)_{MP}^{user} + \Delta t_{PH} + \Delta t_{PF} + \Delta t_{MDC}.$$ 

If the pause (time interval $\Delta_{\text{pause}}$) between the end of the $i$-th $G$-action and the beginning of the next $G$-action exceeds the time interval $\Delta_{\text{MAX}}$, then execution time of the $i$-th $G$-action included in the $G$-operation equals

$$T(i)_G = \Delta t(i)_G + \Delta t(i)_{\text{Exec}} + \Delta t_{RT} + \Delta t_{Re} + \Delta t_{Pr}.$$ 

If the pause between the end of the $i$-th $G$-action and the beginning of the next $G$-action exceeds the time interval $\Delta_{\text{MAX}}, then

$$T(i)_G = \Delta t(i)_G + \Delta t(i)_{\text{Exec}} + \Delta t_{RT}.$$ 

4. Description of the algorithm for predicting the speed of gesture interaction

The above method corresponds to the algorithm, shown in Figure 1 and Figure 2.

In the algorithm shown in Figure 1 and Figure 2, the TOP variable is the duration of a sequence of $F$ $G$-operations, the $lp$ variable characterizes the user experience level, used within the algorithm, and the $ls$ variable characterizes the current level of user mental readiness to perform the $i$-th $G$-action.

The operation of the algorithm begins with entering a list of $G$-operations that must be performed by the user, information about gestures, as well as initial data corresponding to the user experience level $il$ (operators 2 - 7, Figure 1). Statement 8 (Figure 1) sets the initial value of the TOP variable.

Operator 9 (Figure 1) and operator 48 (Figure 2) organize a loop over the variable $f$ to iterate over the $G$-operations included in the $OP$ array. Operator 10 (Figure 1) sets the initial value for the execution time of the $f$-th $G$-operation.

Operator 11 (Figure 1) corresponds to the definition of the cognitive unit $KE$ (a sequence of $G$-actions for performing the $f$-th $G$-operation). To iterate through the $G$-actions that are part of the $f$-th $G$-operation using operator 12 (Figure 1) and operator 42 (Figure 2), a loop is organized over the variable $i$.

Before predicting the execution time of the $G$-action using a loop over the variable $j$ (statements 13 and 17, Figure 1) and conditions (statement 15, Figure 1), the level of user mental preparation to perform the $G$-action, is checked. In statements 18 - 21 (Figure 1), the elements of the $TL$ array are determined (times of execution of $G$-actions included in the cognitive unit $KE$).

In statements 22 - 29 (Figure 1), the first element of the $MNT$ array is determined, depending on the user experience level (the condition in statement 23, Figure 1).

Using a loop over the variable $l$ (statements 30 - 33, Figure 1), the data is prepared for determining the time to prepare for $i$-th $G$-action. The execution time of $i$-th $G$-action is defined in statement 34 (Figure 1). Further (the condition in statement 37, Figure 2), the execution time of the $i$-th $G$-action is specified if it is necessary to pause before performing the next $G$-action.

A pause, depending on duration (the condition in statement 38, Figure 2), can lead to move the hand away from the touch screen and bring the hand to it before the start of the next $G$-action and to specify the execution time of the $i$-th $G$-action (statement 39, Figure 2).
Determination of the duration of the \( f \)-th \( G \)-operation is performed in statement 40 (Figure 2) by summing the duration of the \( G \)-actions. After the end of the enumeration of the \( G \)-actions, included in the cognitive unit to perform the \( f \)-th \( G \)-operation (operator 12, Figure 1), the transition is made to check if there is necessary to pause before performing the next \( G \)-operation (operator 44, Figure 2).

A pause (depending on its duration) in accordance with the condition in statement 45 (Figure 2) may result to take into account additional removing and bring the hand to the touch screen before starting the next \( G \)-operation. In this case, the calculation of the execution time of all \( G \)-operations is performed in statements 46, 47, Figure 1). After the end of the enumeration of all \( G \)-operations (statement 9, Figure 1), the final determination of the execution time of all \( G \)-operations is made.

**Figure 1.** Algorithm for predicting the speed of gesture interaction (part 1).
5. Features of using the algorithm

The initial data preparation for the algorithm, shown in Figure 1 and Figure 2, has a number of features.

Each element of the $OP$ array is the formalized or textual description of the operation that the user must perform by interacting with user interface gestures to implement the functionality of the software application.

Array $T$ contains the average execution times for typical gestures. At the same time, the times for performing gestures depend on the user experience level and should be obtained in advance in the form of average values as a result of the research experiment with groups of users with different experience levels. During the experiment, users perform typical gestures, and observers record the times for performing typical gestures and then determine the average values.

The $MP$ array contains the values of the times of the user's mental preparation for the gesture. The levels of user's mental preparation to perform a gesture depend on their experience level and are also predetermined as a result of a research experiment with groups of users with different experience level.

The $MNT$ array contains the average times for selecting the type of taking the mobile device, selecting the ‘dominant’ hand for the gesture, and selecting the finger for the gesture. The average values of these quantities are also predetermined as a result of the research experiment.
Array $H$ contains the average values of the time to prepare for the gesture, time to move the hand after the gesture, and the response time of the software application to the gesture, which are also predetermined as a result of the research experiment. In statement 11 (figure 1), the sequence of $I$ $G$-actions, required to perform the $f$-th $G$-operation, is determined by selecting an element of the array $ACT$. Each element of the array is also an array and contains the name of the $G$-operation, the user experience level, as well as the sequence of gestures for performing the $G$-operation.

The $ACT$ array is created in advance by conducting the research experiment. Users with different experience levels are assigned to perform an operation with the presentation of the interface prototype. The user uses the interface prototype to define the required $G$-action sequence to perform the operation. The observer records the sequence of $G$-actions. Then, for the same $G$-operation, the sequences of $G$-actions for several users with the same experience level, are analyzed. After that, typical sequences of $G$-actions for the specific $G$-operation are formed. Thus:

$$ACT = \{act(z); z = 1, 2, \ldots, Z\},$$

where $Z$ – number of operations using the user interface that can be performed to implement the functionality of the software application;

$act(z) = \{name(z), lp, a(z, b); b=1, 2, \ldots, B(z)\}$;

$name(z)$ – is a formalized or textual description of the $z$-th $G$-operation;

$lp$ – user experience level;

$a(z, b)$ – $b$-th $G$-action to perform the $z$-th operation;

$B(z)$ – number of $G$-actions to perform the $z$-th operation by user.

Thus, the formation of a cognitive unit $KE$ in operator 11 (Figure 1) consists in choosing the $v$-th ($1 \leq v \leq Z$) element of the $ACT$ array, which corresponds to the $f$-th $G$-operation. In this pattern, $I$ is assigned the value $B(v)$, and in the array $KE$ elements $a(v, 1), a(v, 2), \ldots a(v, B(v))$ are assigned.

6. Conclusion
As a result of the research carried out in this article, the THGLM and KLM models, as well as Fitts' law, have been adapted to user interaction with touch screens of mobile devices. The formulation of the problem for the formation of the algorithm for determining the speed of the user's gesture interaction was made. The list of initial data required for the algorithm to work has been determined. A detailed description of the operation of the algorithm is carried out. The features of preparing the initial data for the algorithm are also considered. At the same time, to prepare the initial data, it is necessary to conduct the research experiment to obtain average values characterizing the temporal components of gestures. The developed algorithm is intended for use at the design stage of the mobile software application that will run on mobile devices with touch screens. The algorithm makes it possible to predict the time spent by users with different experience levels to interact with the user interface of the mobile software application using typical gestures.

7. References
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