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Predicting user performance time for hand gesture interfaces

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ABSTRACT

User interfaces based on touchless hand gestures have advantages over conventional user interfaces in a variety of scenarios. However, they still have challenging problems to be researched, such as the design and evaluation of them in order to obtain satisfactory results. The classical approach of involving users to choose gestures or analyze interface designs needs to be complemented with predictive evaluations for cases in which those user-based methods are inapplicable or expensive to do. Thus quantitative user models are needed to perform those evaluations. THGLM is a model based on KLM and gesture units, but its first formulation needs to be improved. This paper completes the model by analyzing its performance in several user studies. In particular, we found out that THGLM forecasts performance time in doing tasks on UIs based on touchless hand gestures (THG) in an acceptable way (prediction error = 12%, $R^2 > 0.9$). The paper also reports a study concerning the model utility to analyze and compare interface designs. Moreover, the model utility was confirmed by independent designers who were invited to participate in a study. Finally, the initial model was extended by introducing several new operators. As a conclusion, the present model has some intrinsic limitations which are discussed, but the results confirm the general hypothesis that it can be used to analyze UIs based on touchless hand gestures.

Relevance to industry: THGLM should become a useful tool for UI designers to perform usability assessments, improve interface designs, and develop good software applications using THG. This is especially useful in situations where it is difficult to conduct tests with users or as a preliminary step in the process of developing software.

1. Introduction

Current availability of both new body-tracking devices and high-resolution displays has contributed significantly to develop applications that go beyond only entertainment. Inexpensive devices like Kinect, Intel RealSense, or Leap Motion can capture gestures people make with their hands without haptical contact. Therefore, instead of a traditional user interface (UI) based on mice and keyboards we could use an interface based on touchless hand gestures (THG) captured and interpreted by the computer system. Interfaces of this type may be considered as a new class of Natural User Interfaces (NUI) (Wigdor and Wixon, 2011; Webb and Ashley, 2012), and can be advantageous (de la Barré et al., 2009; Walter et al., 2013) in various scenarios. A few examples are sterile environments (e.g., operating rooms (Gallo et al., 2011)), public places where it is not possible or advisable to touch a display (Hinrichs et al., 2013), and classrooms to enhance the quality of education (Jagodziński and Wolski, 2015). Despite interfaces of this type may have great advantages, there are still challenges to address (Norman, 2010). One of these challenges is the design and evaluation of interfaces based on THG in order to develop successful software products; this is the subject of this article.

Designers typically involve users to design and evaluate UIs based on THG. Some of the currently available methods allow choosing gesture sets (Wobbrock et al., 2009; Vatavu, 2012; Nielsen et al., 2004) and understanding interactions with systems (Barclay et al., 2011; Hincapié-Ramos et al., 2014) by considering features like user preferences, memory, or fatigue. These methods allow quantitative evaluation of interfaces based on THG, but this approach requires dealing with the logistic difficulties of doing tests with real users, regarding planning, timing, laboratory setup, recruiting subjects, and conducting experiments. Consequently, a reasonable assumption is that UI designers may find value by adopting predictive evaluations instead of recruiting users,

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especially at early design stages (Erazo et al., 2015) due to the cost of collecting and analyzing data (MacKenzie, 2003; Kieras, 2003).

Given this problem with user testing, designers can use predictive evaluation instead of assessing interfaces by quantifying human performance. Simulation of the biomechanics of human motion (Nunes et al., 2015) is a method which is gaining attention for measuring performance of UI (Bachynskyi et al., 2014). It allows obtaining rich descriptions of users' movements with low cost (Bachynskyi et al., 2014). Moreover, biomechanical simulation has been made more accessible by clustering user muscle activations in interactive tasks (Bachynskyi et al., 2015). These clusters can help designers to estimate muscle loads and user performance in pointing with the arm (Bachynskyi et al., 2015). Another approach that may allow studying more than pointing tasks is the use of predictive models (MacKenzie, 2013) to quantify human performance particularly in terms of time (the period a user takes to accomplish a set of tasks (Card et al., 1980)), which is the focus of this work.

Model-based evaluation has been widely used to analyze interaction problems in HCI especially due to its advantages such as analyzing interface designs and making changes without implementing a real system (MacKenzie, 2003, 2013; Kieras, 2003). Nevertheless, previous models are insufficient to evaluate UIs based on THG due to any of the following causes: they were formulated for other interaction styles (e.g (Card et al., 1980; Cao and Zhai, 2007; Isokoski, 2001)); the extended versions of these models are not applicable to THG (e.g (Holleis et al., 2007; Luo and John, 2005; Lee et al., 2015)), or the feasibility of applying them has not been verified yet (as in the case of (Card et al., 1980; Cao and Zhai, 2007; Isokoski, 2001)); they are constrained to certain type of tasks (e.g. the main use of Fitts' Law (Fitts, 1954) is to analyze tasks of pointing and selecting in the air using a hand (Schwaller and Lalanne, 2013; Pino et al., 2013; Polacek et al., 2012; Zeng et al., 2012) and to compare devices such as Kinect and Wii (Sambrooks and Wilkinson, 2013; Pino et al., 2013; Polacek et al., 2012)). Therefore, new models to evaluate UIs based on THG are necessary. To tackle this problem, some authors have adapted previous models for drawing gestures (Erazo et al., 2015) and derived new ones for optimizing gesture sets based on multi-finger gestures (Sridhar et al., 2015). However, taking into account we are not considering fingers as a first step, Touchless Hand Gesture Level Model (THGLM) (Erazo and Pino, 2015) is an alternative. THGLM is a predictive model based on the assumptions of KLM (Keystroke-Level Model) (Card et al., 1980)—which is a well-known, well validated and relatively easy to use model. THGLM allows forecasting the time to execute a task given a method (expressed using gesture-units (McNeill, 1992; Kendon, 2004) and THG-level actions as illustrated in Fig. 1) and computed using the corresponding formulas. The current state of THGLM is that of a promising model but with incomplete results. Its authors noted that further validation was needed and other operators should be included in order to complete the model (Erazo and Pino, 2015).

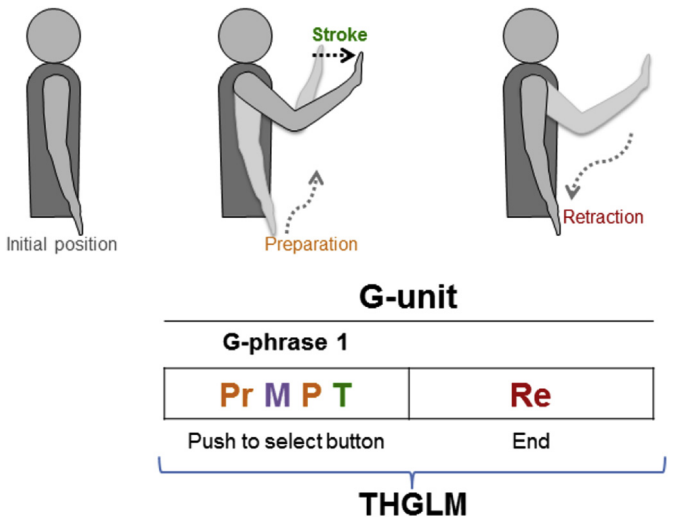

Fig. 1. Example of using THGLM (Erazo and Pino, 2015) which is a model based on KLM (Card et al., 1980) and gesture units (McNeill, 1992; Kendon, 2004) to analyze NUIs based on gestures. The task consists of selecting a button performing a push gesture, departing from a resting position and returning to it. The upper part illustrates the task execution, and the lower part shows the task modeled using THGLM.

Given this landscape, the generic goal of this paper is to complete the initial THGLM proposal (Erazo and Pino, 2015) and study its performance. Our basic research hypothesis to reach this goal is that the final model is a practical tool to help designers in the analysis and design of UIs based on THG. The verification of this general hypothesis relies on the validity of three specific ones: (*H1*) THGLM predicts performance time with acceptable quality, i.e., the values of the used metrics are consistent with those ones reported in the field for similar models; (*H2*) the model allows analyzing UI designs and comparing two or more design options; (*H3*) model predictions remain stable when they are computed by independent designers. If these hypotheses are validated, then THGLM should allow designers of UIs based on THG to predict the performance time required to complete tasks without users' participation, and next, use that value as a metric to assess a user interface. This approach is especially useful in interface evaluations where it is difficult to conduct tests with users or as a preliminary step. Therefore, we expect the model becomes a useful tool for software designers to carry out usability assessments, improve interface designs, and develop better software applications using interfaces based on THG. The main contribution of the paper is then to present a valid and usable model for predicting execution time of hand gestures by adult novice users, provided the hypotheses are confirmed.

The article starts providing the background (section 2) and summarizing the model (section 3). We give further details about THGLM in section 4, especially those related to the use of the mental operator. Then, the model validity is studied in further detail to confirm it makes good predictions (section 5). The use of the model as a tool to analyze interface designs is also included as part of the validation. Section 6 studies the stability of THGLM predictions when independent designers use the model. Next, several operators to be incorporated in the model with their estimated values are described in section 7; also, other operators that may be included in the future are suggested. The article ends with a discussion and the conclusions.

2. Background

2.1. Model-based evaluation

One way to support design and evaluation of UIs is to use model-based evaluation (MacKenzie, 2003, 2013; Kieras, 2003). It is a valuable supplement to conventional usability evaluation that is especially useful for designing, evaluating, or providing a basis to understand interfaces (MacKenzie, 2003), especially at early design stages, before starting to develop the real UI or testing with humans. Model-based evaluation implies using models of how humans would interact with applications. Models can be either descriptive or predictive depending on detail and complexity (MacKenzie, 2013). Descriptive models give designers a framework to describe and reflect on problems qualitatively, whereas

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