

Usability of Vision-Based Interfaces

Cristina Manresa-Yee, Esperança Amengual
Computer Graphics, Computer Vision and AI Group
Mathematics and Computer Science Department,
University of Balearic Islands,
Crta. Valldemossa km 7.5, 07122, Palma, Spain
(+34) 971259721
{cristina.manresa, eamengual}@uib.es

Pere Ponsa
EPSEVG School
Automatic control Department
Barcelona Tech University
Av. Víctor Balaguer 1, Vilanova I la Geltrú, Spain
pedro.ponsa@upc.edu

ABSTRACT

Vision-based interfaces can employ gestures to interact with an interactive system without touching it. Gestures are frequently modelled in laboratories, and usability testing should be carried out. However, often these interfaces present usability issues, and the great diversity of uses of these interfaces and the applications where they are used, makes it difficult to decide which factors to take into account in a usability test. In this paper, we review the literature to compile and analyze the usability factors and metrics used for vision-based interfaces.

Categories and Subject Descriptors

H.5.2. Information interfaces and presentation: User Interfaces – *Interaction styles, evaluation/methodology, user-centered design*

General Terms

Measurement, Design, Experimentation, Human Factors.

Keywords

Vision-based interfaces, usability, gestures, evaluation

1. INTRODUCTION

Human-computer interaction (HCI) is the discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them [1].

When the system “can see” through a camera, the computer is able to acquire information about users and the environment in which they operate [2]. This capability can be used to communicate the user with the computer, therefore obtaining a vision-based interface (VBI).

The system uses computer vision in order to sense and perceive users and their actions within an HCI context. Nowadays this specific type of interfaces are gaining wide acceptance. They analyze and recognize human motion and gestures in real time to use it as an input system in order to interact with the computer, from interacting with the system contactless in an operating room [3] to navigating in virtual reality worlds [4].

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VBIs can be used to identify gestures done by the user by using their own body. A gesture can be a static configuration of a body part, such as a pointing gesture, or it can be a set of dynamic motions of the body or body parts such as a head nodding gesture. Using the user’s own body gestures to interact with a system has been described as natural, direct and intuitive [5]. Nevertheless, there are many criticisms on the naturalism or intuitiveness of these interfaces [6][7] and their usability [8].

Independently of the specific applications that VBI can offer, VBIs frequently include detection, identification and tracking [2]. The detection determines the presence or absence of an element, the identification seeks the recognition of a particular element and the tracking temporally follows an identified element.

On the one hand, when the system replaces a pointing input device (e.g. eye tracking or body parts tracking to replace a mouse [9]) it detects, recognizes and tracks the body part used to interact. And on the other hand, there are other interactive systems that employ gestures as input commands to interact. In this case, reporting the body part position may not be needed [10].

One of the most challenging tasks in VBIs design is the identification of the most suitable gestures for a particular interface. Frequently, gestures are modelled in a laboratory setting where usability testing should be carried out in order to measure the extent to which the designed system can be used by specified users in a specified context of use to achieve specified goals with effectiveness, efficiency and satisfaction [11]. However, the great diversity of uses of these interfaces makes it difficult to decide the factors that should be taken into account in a usability test.

Wickerth et al. [12] proposed a Gesture Usability Scale (GUS), which added to the System Usability Scale (SUS) [13] five questions related to the gesture interface. These items were meant to measure the perceived reliability, performance and compliance with the user’s expectations. Then, in order to define a quantitative model to reflect the usability of a gesture based interface, in [14] the authors presented a model which considered accuracy, fatigue, naturalness and duration. However, other researchers have been using other factors.

The purpose of this paper is to review the current practice in how usability is measured when testing VBIs. The work mines the literature to compile potential factors that could be used to assess usability of VBIs as well as the metrics used to measure them.

The structure of the paper is as follows. The next section describes the factors considered when evaluating VBI and the metrics used to measure those factors. Furthermore, these factors are classified using the ISO 9241-11 attributes: efficiency, effectiveness and

satisfaction. The final section summarizes the key findings and concludes the paper.

2. USABILITY FACTORS

Usability is a term that has been defined by different authors and in different standards [15], but to classify the VBI usability factors found in the literature we will use the three attributes included in the ISO 9241-11, the international standard on Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs), Part 11: "Guidance on usability":

- **Effectiveness** refers to task performance; how accurately and completely did the user achieve the goals?
- **Efficiency** is the amount of effort that is required to achieve the level of effectiveness when achieving the goals. Efficiency is the relationship between effectiveness level and resource consumption.
- **Satisfaction** refers to how comfortable the user feels while using the system.

When searching for works related to our research, the following key words and synonyms were used to search: usability AND ("vision based interface" OR "vision based user interface" OR "gesture based interface" OR "gestural interface" OR "perceptual user interface" OR "natural user interface" OR "natural interface"). Works that did not use computer vision techniques in their system or did not present an evaluation were excluded as we were interested in compiling the usability evaluation factors and metrics.

When designing a gesture for an interface, it is important to consider two different aspects. On the one hand the application's context and the user's requirements [16]. And on the other hand, Lenman et al. [17] characterize gestures along three dimensions: cognitive, technological and articulatory:

- Cognitive aspects are related with how easy a command can be learnt and recalled.
- Technological aspect refer to need of taking into account the state-of-the art of technology, now and in the near future when designing the command set for gestural interaction based on computer vision. To exploit the use of gestures in HCI it is necessary to provide the means by which they can be interpreted by computers [18].
- Articulatory aspects take into consideration that a gesture has to be comfortable to ensure that a physically stressing gesture is avoided taking into account the human anthropometrics [19].

All these considerations have led to a set of factors to assess in a VBI usability evaluation. In the following lines, we will classify the factors found in the literature in **effectiveness**, **efficiency** or **satisfaction** and the metrics used to measure them. At this point, it is pertinent to note that some authors have used other usability definitions, instead of the definition given by ISO 9241-11 that we consider in this work.

2.1 Effectiveness

Effectiveness in VBIs evaluation is assessed mostly by measuring the accuracy and the error rate of the interfaces, which are quantitative measurements.

2.1.1 Accuracy and Error rate

Accuracy is the correctness in recognizing the gestures performed by the user. This factor is related with the robustness and precision of the computer vision techniques. This factor is frequently tested and is an indicator of the gesture uniqueness [14], that is, if a gesture is similar to another one, the system can misinterpret it and trigger a wrong action.

Errors are related with the accuracy and we can distinguish two kinds of errors:

- Misinterpreted gestures within the set of possible gestures, which would be related with the uniqueness.
- Gestures that are not understood, which could be related with the robustness of the computer vision techniques.

A gesture that is not recognized requires repetition, but a gesture which is misrecognized needs to be corrected. In this case, both parameters could be evaluated individually.

A metric frequently used to evaluate accuracy is to control the number of correct recognized gestures regarding the total number of performed gestures [20]. For example, in [10] it is described a test of a hand-based interface to navigate in a 3D world. They prepared a sequence of 40 gestures and 40 people tested the interface, and the accuracy for each gesture was measured using eq. 1.

$$a_{gesture} = \frac{n_{recognized}}{n_{total}} \quad (\text{Eq.1})$$

2.2 Efficiency

When assessing **efficiency**, different measurements are used such as the user's physical and mental effort, duration of the gesture or memorability/learnability.

2.2.1 Physical fatigue

When interacting with body movements, fatigue or tiredness can appear, especially if the gesture is physically demanding. Gestural commands must be concise, fast and avoid gestures that require a high precision over a long period of time in order to minimize effort [21].

Fatigue is a difficult attribute to measure because is user-dependent. The metrics that have been used are usually questionnaires using Likert-scales or Borg CR10 scale (which is a method of rating perceived exertion [22]). For example, in [23] the authors test a nose tracker to replace the mouse and they assess the overall neck effort by using the Borg CR10, with 0 indicating no neck effort and 10 indicating very strong neck effort. Other example is the annex included in ISO 9241-9 [11] which recommends a comfort questionnaire that comprises twelve 7-point interval Likert scale questions about the levels of comfort and effort that are involved in the system's operation such as wrist, arm or shoulder fatigue.

Another way to control the fatigue is by controlling the user's biosignals such as the heart rate or electromyographic signals (EMG). In order to use biosignals, the user will have to set the appropriate equipment to measure them. For example, [24] presents a system based on wearable force sensitive resistors to sense muscle activity. They showed a correlation between the mechanical deformation of the limb (measured through force sensors) and muscle activity, especially fatigue.

2.2.2 Duration

The gesture duration is how long the user needs to perform the gesture. A gesture involves a preparation, an execution and

retraction phase [25]. The execution phase sometimes requires maintaining the gesture for a predefined time for robustness. Duration is strongly related with the computer vision techniques, as a minimum or maximum duration may have been set or can be configured to recognize a gesture. This factor affects the system's efficiency and the user's fatigue: the longer the user needs to perform the gesture, the fatigue can increase and lesser input commands to the system can be performed.

This factor is evaluated by measuring the time between the start and the end of a gesture. In [14] a gesture interface to control a media centre is tested, and to assess the duration they manually computed the time between the start and the end of a gesture. Moreover, many works evaluate this factor by computing the duration of carrying out a task, instead of the actual duration of the gesture, especially when comparing different interfaces. For example, in [23] they compare the time needed to complete a task (the multi-directional tapping task recommended by ISO9241-9[11]) with their VBI and the standard mouse.

2.2.3 Cognitive load

Cognitive load refers to the total amount of mental activity imposed on working memory.

The evaluation of this attribute is frequently done by subjective assessment (questionnaires, e.g. NASA Task Load Index). For example, in [26] authors present a wearable system that recognizes relaxed and discreet as well as large and demonstrative hand gestures. To measure the mental demand, participants were asked to answer the gestural interaction questions of the NASA-TLX [27]. And they also used a 10-point rating scale for these questions to increase their fidelity.

Another approach to evaluate cognitive load is by analyzing the quantity of information that an individual can remember while using that interface. This latter test is based on the idea that when individuals are forced to use working memory or other cognitive resources, information is lost or displaced. The work presented in [30], is an interface for visual navigation of a whole Earth 3D terrain model. Users tested the interface and they were given a memory test to determine if they remembered the symbols they saw, the order of appearance, and where the symbols were located.

2.2.4 Learnability and Memorability

Learnability, or time to learn, is the time and effort required reaching a specific level of use performance. Memorability, or retention over time, is the ease of system intermittently for casual users [19]. The closer the syntax of the operations match the user's understanding the easier it will be to remember how to operate the interface. If the time to learn is fast, then the retention will be less important [28].

To assess this factor, subjective questionnaires are used. For example, in [29] a questionnaire with a 5-point Likert scale was used to assess the easy to learn factor.

In [19] memorability is tested by presenting a slideshow of names of functions in a swift pace, 2 seconds per function. Participants must perform the gesture correctly while the name is displayed, if not, the slideshow restarts and the number of restarts is counted.

2.3 Satisfaction

Most of the factors classified under the **satisfaction** attribute are evaluated by using user questionnaires to capture the subjective users' feelings towards the interface.

2.3.1 Naturalness and Intuitiveness

The naturalness of gestures is related with their quality of being real and not involving anything made or done by people. Intuitiveness is the instinctive use of the gestures based on what one feels they should be even without conscious reasoning. Frequently both concepts are used indistinctly, but intuitiveness can be influenced by previous experiences [30].

Natural and intuitive gestures help the interface to be discoverable by the user, which is a desired factor [16] and influences factors such as learnability, memorability or cognitive load.

Subjective questionnaires are used to assess this factor, but we can also find usability evaluations that assess quantitatively naturalness or other works that focus on finding the most natural gestures.

In Gamberini et al [31], the authors evaluate quantitatively the device's naturalness, based on the identification and analysis of breakdowns in the users' actions when using a locomotion system controlled by the users' feet movements to move in the virtual environment (VE) while remaining seated in a chair. This work is based in Winograd and Flores [32], who defined breakdowns as a crisis in the interpretation of the current situation, which leads a person to suspend his/her action to find a solution.

In [19] two approaches to find gestures that ensure intuitive and logical mapping are used: bottom-up and top-down. Bottom-up takes functions and finds matching gestures, while the top-down presents gestures and finds which functions are logically matched with those. In the bottom-up approach we can also find examples such as the work of Höysniemi et al [33] which analyzes what movements children prefer and are more intuitive in different game contexts (e.g., swimming, running, jumping) by applying a Wizard of Oz approach.

2.3.2 Comfort

Comfort is defined as a pleasant feeling of being relaxed and free from pain.

This factor is frequently assessed by subjective questionnaires (e.g. Likert scales or the Body Part Discomfort (BPD) scale [34]), but we also find works focused on improving this attribute by identifying comfort zones. For example, in Kölsch et al. [35] a method for objective assessment of postural comfort, where postural comfort is defined as a posture that does not elicit compensating motion of other body parts, is presented. The authors analyze the user's posture to define a comfort zone.

2.3.3 Ease of use

Ease of use, easy-to-use or easiness, means that the user needs little effort to operate with the system.

The easier the interface is, the fastest the user will bring out a profit. In order to improve the easiness of a VBI, the design should take into account the previous user experience and the design should be familiar and consistent with the users' expectations [36].

This factor can be evaluated by means of subjective questionnaires. For example in the SUS questionnaire, there is a question regarding the easiness of the system [12].

2.3.4 User experience and Satisfaction of use

The user experience includes both pragmatic (**efficiency** and **effectiveness** attributes) and hedonic aspects of the system, measured through subjective indicators such as user satisfaction and hedonic quality (fun, aesthetics). Hedonic quality is the extent to which a system allows for stimulation by its challenging and

novel character or identification by communicating important personal values [37].

Following this definition, van Beurden et al. [38] assess user experience by a subjective questionnaire with 7-point semantic differential (bad-good, easy-hard) questions to compare gesture-based interaction technologies with device-based interaction methods.

2.3.5 Social acceptance

Various definitions proposed in the literature for social acceptability (also known as social acceptance) are examined in [39]. They synthesize a definition that is based on both how the individual feels about performing the action and how others nearby perceive the users' actions:

- User's social acceptance refers to the positive or negative impression of the task or technology from the user perspective.
- Spectator's social acceptance is a measure of their impressions of the user's actions.

From these two viewpoints, gestures can be said to be socially acceptable if they are deemed to be appropriate, by both the user and any observers, in the context in which they are carried out. It is also possible that users base their social acceptance of a gesture depending on how they would react to the same gesture if they were a spectator, thus creating interlinks between user's social acceptance and spectator's social acceptance.

As pointed out in [40], because the set of gestures that can be reliably recognized may be quite different from the set of gestures that users are willing to adopt, the social acceptability of using any given gesture must be evaluated before time and effort are spent implementing them. Individuals evaluate social acceptability when the motivations to use the technology compete with the restrictions of social settings.

There are many possible factors that should be examined in social acceptability, such as culture [41], discreteness, time, gesture performance, personality traits, user's age group, location and audience. In order to understand how these factors influence social acceptability, there have been different initiatives to evaluate how they affect user willingness to perform gestures [38][40]. These evaluations consist on examining a set of well-defined gestures by performing surveys to different groups of participants who have to answer some questions after watching a video of a particular gesture. For example in [42], an interface to use in meetings using touch and gestures is tested, and social acceptability is assessed by subjective questionnaires.

3. CONCLUSIONS

The use of VBIs has expanded and they have become a mainstream technology especially in leisure contexts. The widespread use of this particular type of interfaces leads us to consider their usability as an essential attribute to be satisfied to ensure the success of the wide range of applications using VBI which are available nowadays. However, due to the novelty of these interfaces, their interaction design is still immature and standard guidelines are not yet available. New usability metrics could be proposed in order to improve the design and implementation of these interfaces.

In this work we have reviewed the current practice in how usability is measured when testing VBIs. In order to classify the different factors that could be considered for usability assessment in VBIs we have mined the literature and present a taxonomy

based on the three attributes of usability as defined in ISO 9241-9 [11]: effectiveness, efficiency and satisfaction. Each one of these attributes has been divided into different factors that have been analyzed in order to gather existent metrics used to measure them. In table 1, we summarize the key findings of this work.

Future work lines will include the definition of new and appropriate factors and metrics to assess usability aspects of VBIs.

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Table 1. Summary of the usability factors and metrics

Attributes	Factors	Definition	Metrics
Effectiveness	Accuracy and error rate	Correctness in recognizing the gestures	Number of recognized gestures regarding the total number of performed gestures
Efficiency	Physical fatigue	Tiredness that appears when interacting with body movements	Subjective assessment (Likert-scales, Borg CR10 scale) User's bio signals
	Duration	How long the user needs to perform the gesture	Time between the start and the end of the gesture
	Cognitive load	Total amount of mental activity imposed on working memory	Subjective assessment (Likert-scale, NASA Task Load Index) Quantity of information that an individual can remember while using the interface
	Learnability and memorability	Learnability, or time to learn, is the time and effort required reaching a specific level of use performance. Memorability, or retention over time, is the ease of system intermittently for casual users	Subjective assessment Number of restarts of a slideshow naming a function and the user performing the related gesture. If the user does not perform the gesture correctly, the slideshow restarts.
Satisfaction	Naturalness and intuitiveness	Naturalness is related with their quality of being real and not involving anything made or done by people. Intuitiveness is the instinctive use of the gestures based on what one feels they should be even without conscious reasoning	Subjective assessment Analysis of breakdowns Bottom-up approach: takes functions and finds matching gestures, Top-down approach: presents gestures and finds which functions are logically matched with those
	Comfort	Comfort is defined as a pleasant feeling of being relaxed and free from pain.	Subjective assessment (Likert-scale, Body Part Discomfort (BPD)) Define the comfort zone
	Ease of use	Little effort to operate with the system	Subjective assessment
	User experience and Satisfaction of use	Pragmatic and hedonic aspects of the system	Subjective assessment
	Social acceptance	Appropriateness of the gesture, by both the user and any observers, in the context in which they are carried out	Subjective assessment