Seeing through the Kinect: A Survey on Heuristics for Building Natural User Interfaces Environments

Vanessa Regina Margareth Lima Maike[1], Laurindo de Sousa Britto Neto[1,2], Maria Cecília Calani Baranauskas[1], and Siome Klein Goldenstein[1]

[1] Institute of Computing, State University of Campinas (UNICAMP), Campinas, Brazil
[2] Departament of Computing, Federal University of Piauí (UFPI), Teresina, Brazil
vanessa.maike@gmail.com, laurindoneto@ufpi.edu.br, {cecilia,siome}@ic.unicamp.br

Abstract. The idea of interacting with technologies through touch-less and body-based interfaces has caused great excitement amongst users, but for the designers it has created various new challenges. Usability encompasses part of these challenges, and there have been attempts at creating heuristics for NUIs design. However, most of these heuristics consider using a device such as Kinect for the recognition of gestures, not people or objects. Therefore, in this paper we investigate the subject by presenting a systematic literature review aimed at finding heuristics for the design and evaluation of NUIs. Our analysis focuses on the scenario of helping people with visual disabilities in their daily activities. By looking at the state of the art, we intend to verify how many and which heuristics fit in this context.

Keywords: Human-Computer Interaction, HCI, Accessibility, Assistive Technologies.

1 Introduction

Consider a scenario in which a blind professor is working in her office facing the computer while leaving her office door open. Meanwhile, a Microsoft® Kinect, a camera capable of capturing videos with color and depth information, faces the door and is connected to the computer As soon as someone walks into the room, the system recognizes the person as one of the professor's coworkers or students, and signals in accordance to some prior configuration, such as saying the person's name or chiming a person-based sound snippet. Later that day, someone walks by the office and waves at the professor. The system recognizes the gesture as a way of saying hello, and tells the professor someone in the corridor has sent a greeting.

This scenario describes some of the possible uses for the new paradigm in Human Computer Interaction (HCI) that has become known as Natural User Interfaces (NUIs). The idea of interacting with technologies through touch-less and body-based interfaces has caused great excitement amongst users, but for the designers it has created various new challenges [14]. Usability encompasses part of these challenges, and there have been attempts at creating heuristics for NUIs design [7, 19]. However,

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2014, Part I, LNCS 8513, pp. 407–418, 2014.

most of these heuristics consider using a device such as Kinect for the recognition of gestures, not people or objects. For instance, [7] propose guidelines for touch-less gestural interaction, looking to the gestures as specific commands, not as day-to-day actions that need to be interpreted. Therefore, in this paper we investigate the subject by presenting a systematic literature review aimed at finding heuristics for the design and evaluation of NUIs. Our analysis, however, will be focused in the context of helping people with visual disabilities with their daily activities, such as walking, translating textual information (e.g. signs, symbols, plaques...), or recognizing people and objects. By looking at the state of the art, we intend to verify how many and which heuristics fit in the scenario described previously.

The paper is organized as follows: section 2 will summarize a previous systematic review made about the use of the Kinect as an assistive technology; section 3 will detail the methodology applied in this systematic review; section 4 will present the main results; finally, section 5 will discuss these results and conclude.

2 Kinect as an Assistive Technology

Previous to the review presented in this paper, we conducted a preliminary systematic review, with the purpose of answering the research question: "*How is the Kinect being used to assist people with visual impairments?*" A search was conducted by applying the keywords "Kinect" and "blind" in both ACM and IEEE digital libraries. This search returned 105 results, from which only 19 were relevant to answer the research question. The publication years of these 19 papers ranged from 2011 to 2013.

The analysis of the obtained papers involved characterizing the participants and the devices used in the studies. The review included papers that either showed work involving the Kinect assisting users with some sort of disability, or other device used to assist visually impaired people. Papers that did not meet these criteria or that did not present user evaluation were discarded. The following list summarizes the types of data that were extracted from the 19 selected papers, and then Table 1 summarizes the actual data that was extracted using these questions.

1. What was the device used in the study?
2. Where does the user place the device?
3. How does the device provide feedback to the user?
4. Can the user send commands or feedback to the device?
5. What is the type of disability that the study deals with?
6. Did the user evaluation involve users with disabilities?
7. Are the test users people with real or simulated disabilities?
8. How many test users were involved?
9. How many test scenarios were applied?
10. Was the impact of the proposed solution measured by comparing it with other solutions?

Table 1. Data extracted during the first exploratory systematic review

Data	Summary of Extracted Data
Device used	**Kinect:** 55%; **iPad:** 10%; **Wii Mote:** 10%; **Others:** 25% (include robot, interactive map, TOF camera, and wearable haptic devices)
Location of the Device	**Head:** 31%; **Waist:** 15%; **Hand:** 23%; **Table:** 31%
Feedback provided	**Sound:** 32%; **Tactile:** 47%; **Other/None:** 21%
Does User interact?	**Yes:** 33%; **No:** 67%
Disability type	**Visual:** 88%; **Cognitive:** 12%
Are Users with disabilities involved?	**Yes:** 47%; **No:** 53%
Are disabilities real or simulated?	**Real:**46%; **Simulated:** 23%; **Both:** 15%; **None:** 8%; **Unspecified:** 8%
# Test users	**Average:** 7; **Minimum:** 2; **Maximum:** 28
# Test scenarios	**Average:** 2; **Minimum:** 1; **Maximum:** 4
Is the study compared with other solutions?	**Yes:** 32%; **No:** 68%

This data helped in understanding the current scenario in the research field of using NUIs for assisting people with disabilities. The characteristics extracted from the studies represent what we believe are the key points to pay attention to when developing a new solution for assistive technology. Thus, three specific aspects lead to important conclusions. First, the data shows a clear tendency towards tactile feedback. Also, amongst the studies that used sound feedback, none utilized 3D sound, which is an interesting form of feedback to explore since it provides a sense of direction and angle. Furthermore, a combination of two types of feedback (tactile and sound) could be explored. Second, the extracted data shows that many studies involved only users with simulated disabilities (e.g., blindfolded people instead of real blinds) in the evaluation phase. Working with real users is extremely important, because they already have their own strategies to deal with their disabilities, which may conflict or not be supported by the proposed solution. On the other hand, users with simulated disabilities are representing users with a recently acquired disability, i.e., a completely different category of user. Therefore, it is important to involve both types of users in the design process of any novel assistive technology. Third, the very low number of studies that had solutions in which users could somehow interact with the system, instead of just receiving feedback, can be a consequence of the novelty of this research field. Most papers were about solutions driven almost exclusively to very specific tasks – an indicative that they are being tested in limited contexts, instead of wide ones. This allows the specialization of the solution, perfecting it for its intended task, but it also limits its applications and possibility of usefulness to real users.

Therefore, the current scenario of NUIs as technologies for assisting people with disabilities is still in its early stages. To push the research field forward and develop solutions that are truly helpful to visually impaired people, it is important to involve real users throughout the design and evaluation process. Prior to that, however, it is essential to better understand the current Natural User Interfaces; what are their strengths and their limitations, and how they can best be used. Therefore, a set of heuristics for NUIs could help designers and developers in creating solutions that best explore this new category of interface. The next sections show how we came to a set of heuristics for NUI, with the scenario of assisting visually impaired users in mind.

3 Research Methodology

In this paper we adopted the PRISMA statement [10] to organize a systematic review in which we tried to answer the research question: "*What heuristics for NUIs could inform the design and evaluation of assistive technology for visually impaired people?*" The audience considered in this work was that of technology users, including visually impaired people (blind and low vision). The intervention to be created is a set of heuristics (guidelines) for the design and evaluation of Natural User Interfaces (NUIs) as an assistive technology for users with visual impairments. The control group is the already established usability, design and evaluation heuristics for computer interfaces [13]. The expected results are the aforementioned set of heuristics, and they are expected to be useful for both NUI designers and HCI researchers.

3.1 Eligibility Criteria

The inclusion (I) and exclusion (E) criteria for the papers were the following:

- (I) It presents design or evaluation of novel NUIs;
- (I) It presents information that might be relevant to establish heuristics for NUIs;
- (E) It does not present relevant information regarding heuristics for NUIs;
- (E) Its publication date is older than 2004.
- (E) Its search result was related to entire proceedings or magazines, not to specific entries;

The last criterion was created because there were many search results, especially from the ACM digital library, that included generic references to conference proceedings or entire magazines, without specifying any article. It was decided that these results could be discarded after realizing that the specific item within the proceedings or magazine that met the search criteria would also show up as an individual search result, eliminating the need to search through the entire proceedings or magazine. The language restriction for the selection of studies was papers written in English or in Brazilian Portuguese. There were restrictions regarding type of study or what Liberati et al. [10] refer to as PICOS.

3.2 Information Sources and Search

The last search was performed on January 2014. The sources of information utilized were the following digital libraries: ACM, IEEE, Springer, Science Direct and Scopus. Manual search was not immediately discarded, but ultimately it was not used. The ACM Digital Library (http://dl.acm.org) comprehends all publications from the

Association for Computing Machinery (ACM), a total of 402,435 full papers (as of early 2014). The IEEE digital library (http://ieeexplore.ieee.org) contains the 3,675,903 (as of early 2014) publications from the Institute of Electrical and Electronics Engineers (IEEE). The Springer digital library (http://link.springer.com) contains over 8 million resources published by Springer Science+Business Media, the majority consisting of articles and book chapters. Science Direct (http://www.sciencedirect.com) is a full-text scientific database that offers journal articles from more than 2,500 journals and book chapters from almost 20,000 books, making a total of over 12 million resources. Finally, Scopus (http://www.scopus.com/) is an abstract and citation database of peer-reviewed literature, covering more than 50 million records, 21,000 titles and 5,000 publishers from the fields of science, technology, medicine, social sciences and arts and humanities.

There were two search terms used in parallel: "NUI Usability" and "NUI Heuristics". Except for the search results from Springer, in all other sources the title, abstract and keywords of every search result were read. In the case of Springer, before reading these informations, two search filters were applied: first, the chosen "Discipline" was "Computer Science", and second, the "Subdiscipline" was "HCI" (Human-Computer Interaction).

3.3 Study Selection and Data Collection

The first step in the strategy for study selection was to identify duplicated search results, since multiple search engines were used. After that, the inclusion and exclusion criteria were applied by reading the title, abstract and the keywords and by looking at the publication year of the papers that came up as search results.

A data extraction form was created to apply to each selected study. The following table details the contents of this form.

Table 2. Data extraction form for the systematic review

Field Name	Type	Options
Type of study	Pick many list	Qualitative Research Quantitative Research Others
Heuristics Proposal	Pick one list	Proposes heuristics and evaluates them Only evaluates heuristics proposed by others Only proposes heuristics Does not propose heuristics directly but allows inference Does not propose heuristics and does not allow inference
User Testing	Pick many list	Visually impaired users Users with other types of disabilities Users without disabilities Users with simulated disabilities Does not have user testing

Table 2. *(continued)*

Device Testing	Pick many list	Kinect Other devices Does not use specific devices
Heuristics drawn from this study	Text	-

The adopted strategy was to first skim each paper, looking for sections in which there would probably be either heuristics proposals or information that suggests heuristics (such as design decisions, learned lessons, or user evaluation strategy and results). Then, these sections were carefully read searching for these kinds of information, which were annotated in the last field of the extraction form. The remaining fields would then be filled either during the skimming or the careful read. However, if that did not happen, then a new skim would be made on the paper, now looking for the missing information.

3.4 Risk of Bias in Individual Studies

It is very common in HCI papers that present a novel design to first present the design, then describe a user evaluation, apply a statistical analysis to it and assume the numbers prove the design was successful. Although this is a valid method, it carries great risk of bias, especially depending on which aspects of the user evaluation the authors applied their quantitative analysis. Therefore, during the data extraction step of this systematic review, most of the information was taken from design decisions, qualitative analysis or discussion of results. Quantitative analysis was considered, but only when directly related to a specified heuristic being evaluated or when this quantitative data was associated with some qualitative assessment.

3.5 Summary Measures

The heuristics drawn from each selected study presented patterns, either by the use of identical words in different papers (such as comfort or fatigue), or by reporting similar issues or recommendations regarding NUIs (even with NUIs that were related to different devices and interaction methods). Therefore, as the data extraction process progressed, the drawn heuristics were gradually being separated into categories.

3.6 Synthesis of Results

The data extraction forms utilized were embedded in the tool used for this systematic review, named StArt (http://lapes.dc.ufscar.br/tools/start_tool). This allowed for automatic generation of statistics, at least for the selection step of the systematic review and for the analysis of the first four fields of the data extraction form. As for the last field (“Heuristics drawn from this study”), the analysis process was manual and gradual, as the data extraction occurred. When all data was gathered, a final organization was necessary to remove redundant or inconsistent information.

3.7 Risk of Bias Across Studies

We tried to avoid publication bias by selecting what we believed were the main digital libraries currently available. Even so, there may be two types of bias in this systematic review. First, the filters applied in the Springer search engine may have removed studies that were either incorrectly categorized or that were not from the field of HCI but provided useful information for the establishment of NUI heuristics. Second, as explained in section 3.5, the strategy adopted for data extraction was to skim the papers. This may result in important information being overlooked or neglected, especially if the paper mixed heuristics or qualitative information with technical information.

3.8 Additional Analyses

Additional analysis was necessary to evaluate the obtained heuristics through the perspective of accessibility and assistive technologies. This means assessing which heuristics apply to every kind of user and which do not apply or apply only to users with disabilities. However, Universal Accessibility was kept in mind to provide, as much as possible, heuristics that did not discriminate types of users.

4 Results

The database search returned a total of 457 results. The following graph shows the percentage of studies that were duplicated, rejected and accepted to the data extraction phase. Next, Table 3 shows the heuristics drawn from this systematic review.

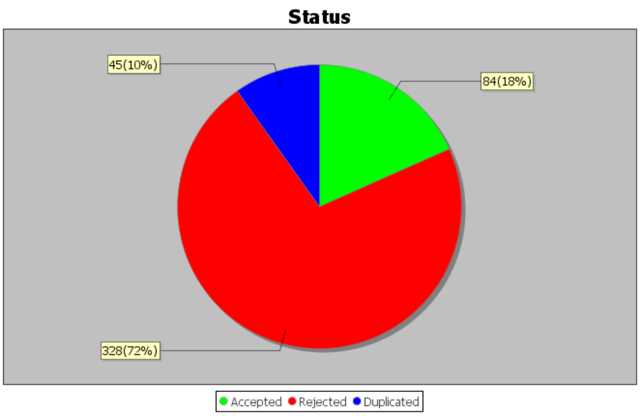

Fig. 1. Numbers for the selection phase

Table 3. Categorized heuristics for NUI

Interaction
1. **Operation modes:** provide different operation modes, each with its own primary information carrier (e.g., text, hypertext, multimedia…).. Also, provide an explicit way for the user to switch between modes and offer a smooth transition. [8, 9, 21]
2. **"Interactability":** selectable and/or "interactable" objects should be explicit and allow both their temporary and permanent selection. [1, 3, 9]
3. **Accuracy:** input by the user (e.g., gestures) should be accurately detected and tracked. [1, 4, 13, 19, 16]
4. **Responsiveness:** the execution of the user input should be in real time. [3, 4, 13]
5. Identity: sets of interaction metaphors should make sense as whole, so that it is possible to understand what the system can and cannot interpret. When applicable, visual grouping of semantic similar commands should be made. [1]
6. **Metaphor coherence:** interaction metaphors should have a clear relationship with the functionalities they execute, requiring a reduced mental load. [3, 4]
7. Distinction: interaction metaphors should not be too similar, to avoid confusion and facilitate recognition. [19]
8. **Comfort:** the interaction should not require much effort and should not cause fatigue on the user. [1, 3, 4, 5, 12, 18]
9. **Device-Task compatibility:** the tasks for which the NUI device is going to be used have to be compatible with the kind of interaction it offers (e.g., using the Kinect as a mouse cursor is inadequate). [3, 19, 21]
Navigation
10. **Guidance:** there has to be a balance between exploration and guidance, to maintain a flow of interaction both to expert and novice users. Also, shortcuts should be provided for expert users. [1, 6, 9, 18]
11. **Wayfinding:** users should be able to know where they are from a big picture perspective and from a microscopic perception. [9, 18]

Table 3. *(continued)*

12. **Active Exploration:** to promote the learning of a large set of interaction metaphors, a difficult task, active exploration of this set should be favored to enhance transition from novice to expert usage. [1, 2]
13. Space: the location in which the system is expected to be used must be appropriate for the kinds of interactions it requires (e.g., full body gestures require a lot of space) and for the number of simultaneous users. [8, 19]
User Adoption
14. **Engagement:** provide immersion during the interaction, at the same time allowing for easy information acquiring and integration. [8, 9]
15. **Competition:** in comparison with the equivalent interactions from traditional non-NUI interfaces, the NUI alternative should be more efficient, more engaging and easier to use. [17, 18, 19]
16. **Affordability:** the NUI device should have an affordable cost. [18]
17. **Familiarity:** the interface should provide a sense of familiarity, which is also related to the coherence between task and device and between interaction metaphor and functionality. [1, 3, 13]
18. **Social acceptance:** using the device should not cause embarrassment to the users. [3, 5, 19]
19. Learnability: there has to be coherence between learning time and frequency of use; if the task is performed frequently (such as in a working context), then it is acceptable to have some learning time; otherwise, the interface should be usable without learning. [2, 10, 19]
Multiple Users
20. **Conflict:** if the system supports multiple users working in the same task at the same time, then it should handle and prevent conflicting inputs. [1, 2, 8, 10, 13, 19]
21. Parallel processing: enable personal views so that users can each work on their parallel tasks without interfering with the group view. [2, 13]

Table 3. *(continued)*

22. Two-way communication: if multiple users are working on different activities through the same interface, and are not necessarily in the same room, provide ways for both sides to communicate with each other. [21]
23. Learning: when working together, users learn from each other by copying, so it is important to allow them to be aware of each other's actions and intentions. [2]

5 Discussion

In this section we present a brief analysis of the obtained heuristics from the perspective of accessibility and universal access, and finalize with our concluding remarks.

5.1 NUI Heuristics and Accessibility

The set of 23 heuristics shown in Table 3 was compiled bearing in mind two key aspects: embracing any NUI technology and following universal access. For this reason, we avoided using any terms that are specific to certain interfaces, such as "gesture" and "screen". Although the studies that served as theoretical basis did, in most cases, present works and conclusions based upon certain NUIs, we tried to look at their proposed guidelines, learned lessons and recommendations from an impartial perspective. This is a double-edged blade, as it may lead to heuristics that do not apply to every NUI (especially to NUIs that were not invented yet), but at the same time is meant to be of help to any NUI designer or HCI researcher.

Regarding universal access, we believe all heuristics are adequate to any kind of user, although some heuristics have a more evident contribution to assistive technologies. This last remark is especially true if we consider the scenario depicted in section 2. The lack of proposed solutions that do not allow for users to send interactions to the system can be remedied by heuristic 1 in Table 3. Providing different modes of operation with distinct information carriers implies offering not only multiple forms of communication (system to user and vice-versa), but also different types of feedback that can each be suitable to a kind of disability. Furthermore, all the heuristics in the "User Adoption" group are essential when thinking of new assistive technologies. First, because users who already live with their disabilities in a long time already have their own strategies to dealing with it, so a new technology must offer really good advantages to them. Second, because many solutions are developed keeping in mind only the novelty of the technology behind it, and not necessarily if it will actually be acceptable to users in their daily lives.

5.2 Conclusions

This paper presented the methodology adopted to make a systematic review with the goal of answering the research question "*What heuristics for NUIs could inform the design and evaluation of assistive technology for visually impaired people?*" It also presented a set of 23 heuristics for NUIs, resulting of this literature review.

This set of heuristics is intended to help both designers and HCI researchers working with NUIs. They represent an interpretation of the designs and user evaluation results of several researches from the last 10 years. Therefore, they are not to be taken as a rigid set of rules, but a guide to design NUIs that can care to all types of users.

Acknowledgements. We would like to thank the Institute of Computing (IC) from UNICAMP, Microsoft®, Fundação de Amparo à Pesquisa do Estado de São Paulo (Fapesp), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Departament of Computing from the Federal University of Piauí (UFPI) for their support in the development of this work.

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