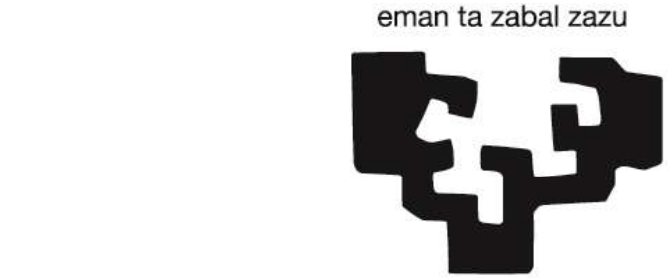

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Assisted Interaction for Improving Web Accessibility: An Approach Driven and Tested by Users with Disabilities

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Abstract

The Web has become an essential tool for the daily lives of millions of people. Today, an increasing percentage of the world's population depend on this global information system to work, socialise, and entertain themselves among many other activities. The benefits of the Web are even more crucial for people with disabilities as it allows them to perform some tasks that are restricted for them in the physical word due to the plethora of accessibility barriers. Consequently, their opportunities for social integration as free and equal citizens are hindered. Despite their advantages, most web pages usually ignore the special needs of people with disabilities. Many of them usually include a single design to fit all users, making it more difficult to adapt the web interface to the personal needs. Diverse methods have been proposed to combat this problem. For instance, transcoding systems aim to automatically transform inaccessible Web pages on the fly into accessible ones. In order to improve web accessibility to specific groups of people these methods require information about the most suitable adaptation techniques that should be applied to each one.

This thesis collects a number of in-depth studies about the suitability of adaptation techniques to improve the web navigation for two different groups of people with disabilities: people with motor impairments and people with low vision. Based on literature reviews and observational studies different sets of adaptations have been implemented and evaluated with users both in-situ during single session laboratory experiments and remotely from participants' homes during a longitudinal study. The RemoTest tool was used to assist designing and conducting experimental sessions, as well to gather interaction data from participants. The interaction environments created by the RemoTest were previously evaluated and the results revealed that these were accessible to conduct inclusive experiments both in remote and in-situ contexts.

Various interface adaptations and alternative interaction methods were evaluated in different contexts by means of qualitative and quantitative analysis of participants' performance and satisfaction. Transcoding techniques were evaluated with tablet users with reduced mobility. The results showed that the majority of the participants preferred the adapted interfaces even if some disadvantages were associated to these. Web adaptations techniques were also evaluated with people with low vision using desktop computers. The results showed that the advantages of some adaptations techniques varied depending on the type of assistive technology used by the participants to access the Web. Two cursor enhancements for assisting link selection to people with motor impairments were evaluated with users of different alternative pointing devices.

The results from a preliminary laboratory study showed that the majority of participants with motor impairments improved effectiveness and efficiency on point and click trajectories with one of the two tested cursor enhancements. These results depended on the alternative pointing device used, as well as on subjective preferences. A subsequent longitudinal study showed an improvement in the performance with the cursor enhancements over time.

Contents

1. Summary

1.1. Introduction

Since the Web was first introduced to the public three decades ago [3], this global information system continues to evolve and has become unavoidable in much of our lives. An increasing percentage of the world's population constantly takes advantage of the Internet to perform a wide variety of activities in areas as diverse as education, work, business, entertainment, or public administration, among many others. In addition to the clear advantages that the Web provides to its users, it also promotes the inclusion of some human groups such as people with disabilities. These people frequently find barriers to carrying out several activities in the physical world that hinder or even make impossible their social inclusion and participation. For many of them, the Web provides a valid alternative with which to carry out these activities.

In the early 1990s the challenge was to achieve the technological infrastructure for the Web to work. Nowadays, one of the main concerns is to design web sites that meet the needs of the people who use them [9]. Despite the many guidelines, recommendations and policies [4]–[7][13] that have been developed to promote accessibility to the Web for people with disabilities, this is a challenge that has not yet been overcome [8]. The majority of websites present rigid designs for all users, which cannot be accommodated to the specific needs of the different users with disabilities. Even if a website is fully conformant to strict accessibility guidelines it is likely that not all users with special needs will get the best user experience. This happens when the user interface cannot be adapted to their own needs, preferences, characteristics, and even to their own equipment.

Some interesting solutions that allow the user to personalize certain aspects of a website to improve its accessibility can be found in the literature. However, these

are frequently limited and are mainly focused on specific features such as proposed colour schemes or font sizes to meet the needs of some people with visual disabilities. There is, therefore, a shortage of general-purpose proposals that are, at the same time, tailored to the specific needs of each user, covering an ample range of disabilities.

In this sense, an interesting approach is transcoding systems, which allow automated adaptation of inaccessible web content and structure on the fly into accessible pages, without needing the intervention of the authors to modify their pages [2].

Users with limited dexterity in upper limbs may have difficulties to manipulate graphical user interfaces. The largest barrier is frequently the use of pointing devices to select, click, drag, etc., items. There exist in the literature different pieces of software that create virtual devices implementing alternative interaction methods to assist target selection.

This thesis work starts from these two approaches, trying to provide a systematic framework for selecting, adapting, measuring and evaluating their use, in order to improve the user experience on the Web of two groups of people with special needs: people with motor impairments and people with low vision.

1.1.1. Coherence of the thesis work

This thesis work presents six papers published in diverse international prestigious journals and conferences. All of them form part of a sequential research work with the same objectives and methodology. The common objective is to improve Web accessibility for people with disabilities by means of the use of adaptation techniques and cursor enhancement applications. The general methodology is centred in the study of the behaviour of real users that would later feed user models.

For this purpose, a recursive scheme has been followed in the work presented in this thesis. This scheme always included:

- a literature review for selecting suitable adaptation techniques and cursor enhancement applications
- observation of real users behaviour to detect the problems and barriers they find when accessing the Web
- selection and adjustment of the most suitable aids and
- evaluation of the adaptations and enhancements with users

As a result, this thesis presents an evolving research work that builds a number of proposals for web accessibility advancements supported in evidence obtained from the experimentation with users.

1.2. Methodology

Even though the work presented in this thesis has been developed as a sequence of concatenated research activities, the methodology adopted is coherent and common to the whole work. We followed User-Centred Methodology, as described in the next paragraphs:

1. All the activities commenced with a rigorous study of the needs and characteristics of the selected target user population. These studies have taken different forms depending of the type of research. Users with special needs were observed while interacting with selected web pages, as well as interviewed in order to obtain knowledge of their accessibility problems.

2. After that, a literature review was always conducted to seek, select, and evaluate:
    a) relevant guidelines and standards for the selected group of users and
    b) suitable web accessibility supportive techniques for these users.

3. Taking all this information as a starting point, we tackled the development of techniques and aids based on the previous findings, applying User-Centred Design techniques. In all the works, we followed the principles of usability and accessibility to favour their acceptance and to maximize their compatibility with:
    a) the equipment on which the tests are carried out (always allowing users to use their own personal equipment, this being well adapted to their characteristics and needs).
    b) any type of web page in order to foster free navigation in subsequent experimental tasks.

    In most cases this phase involved the design of pieces of software, including interface adaptations and interaction aids, or complete user-testing environments, such as the RemoTest platform, co-designed with other researchers, in order to carry out tests with users and gather interaction data. To this end, the following was required:

a) the definition of the types of data and other parameters such as the sampling frequency, necessary to be able to subsequently evaluate the performance achieved with the adaptations and aids being tested.

b) the design of accessible questionnaires to collect subjective assessments of participants on the evaluated techniques.

4. All the proposed advancements have been formally evaluated with the collaboration of users. For each experiment the following tasks have been performed:

    a) definition of the tasks for the different tests carried out with users (specific activities on the Web to evaluate the use, targeted selection of objectives to evaluate performance, subjective evaluation based on questionnaires).

    b) carrying out qualitative studies that include the analysis of:
        - subjective evaluations of the participants –through usability questionnaires, and their behaviour
        - users' comments obtained by the thinking aloud technique and recording their interaction on video

    c) performing quantitative studies that include the analysis of aspects relating to the performance of the participants, based on different measures of human performance collected from the literature.

    d) conducting supervised single-session studies in order to assess the acceptance (through usability questionnaires) and the achieved performance (by measuring the effectiveness and efficiency of users completing tasks).

    e) making statistical analysis of the data gathered to assess the significance of the results achieved. For instance, in order to compare the effectiveness of different variants tested through relevant statistical tests. On the other hand, the degree of usability of the proposed aids was measured by means of subjective evaluations of the participants answering SUS questionnaires.

The experiments with users have obtained the prior approval of the University Ethics Committee that requires justification of the studies with human beings and ensures the correct treatment of the personal data. The methodology to be used in this research work was also approved by evaluating the type of study (qualitative or quantitative), sample size, types of users (grouped according to type of disability, assistive technology used to access the computer, control users without disabilities), collected data, study variables, and model of analysis of results.

1.3. Objectives

The main objective of this thesis is to contribute to the knowledge about the characteristics and needs of users with specific disabilities, people with upper limb motor restrictions and people with low vision, in order to propose suitable methodologies, procedures and software tools to enhance their use of digital applications.

This objective has been structured in a number of sub-objectives:

1. To analyse the needs of users with motor disability and people with specific disabilities (upper limbs motor restrictions and people with low vision).
2. To search, classify, analyse, adapt and test support aids and adaptations, which assist people with specific disabilities to use the web.
3. To develop and test evaluation tools for the accurate measurement of the patterns of use and the validity of the proposed aids.
4. To develop support aids and adaptations which assist people with specific disabilities to use the web.
5. To conduct studies including users with disabilities in order to test and evaluate the quality and validity of the previously selected and developed technical helps.
6. To propose criteria to enhance web accessibility for the selected groups of users.

Objective 1 has been addressed in publications [14] and [10]. In paper [14], a user study with people with motor impairments was conducted to detect their main interaction characteristics by means of different performance measures about rapidity and accuracy of cursor movement. In paper [10], navigation strategies of users with low vision were studied by means of an observational study in order to detect the appropriate web adaptation techniques for them.

Objective 2 has been addressed in publications [15], [10], [11] and [12]. In paper [15], appropriate adaptation techniques and alternative interaction methods to assist web navigation on touch screen tablets for people with reduced mobility in upper limbs were gathered from the literature. In paper [10] a set of adaptation techniques aiming to assist web navigation for users with low vision were collected from the literature. In papers [11] and [12] several cursor enhancements to assist point and click interactions for users with motor impairments were reviewed from the literature.

Objective 3 has been addressed in publications [14] and [1]. In both papers the RemoTest platform to assist experimenters performing user tests was presented. In paper [14], the platform was applied to conduct a formal user test. In paper [1],

the accessibility of the environments created by RemoTest (installation process, questionnaires, task description) was evaluated by means of formal in situ user studies with participants with diverse disabilities.

Objective 4 has been addressed in publications [15], [10], [11] and [12]. In paper [15], a set of interface adaptations and alternative interaction methods were developed for assisting people with motor impairments using touch screen tablets. In paper [10], a set of adaptation techniques aiming to assist web navigation for people with low vision were developed. In papers [11] and [12] two different cursor aids were developed for assisting link selection to people with motor impairments.

Objective 5 has been addressed in publications [15], [10], [11] and [12]. In papers [15], [10] and [11] different *in situ* user tests were conducted in order to evaluate the diverse technical assistances proposed for each specific group of people with disabilities. In paper [12], a longitudinal study was conducted with users with motor impairments, in order to study the learning effect on their performance and their satisfaction with the cursor aids being tested. In this study, the users participated from home in order to obtain more naturalistic interaction data from everyday computer use.

Objective 6 has been addressed in publications [15], [10] and [12]. Based on the results of each study, different improvements were proposed for the technical assistances being tested in each case.

1.4. Results

1. Unusual patterns on point and click tasks were detected and different user profiles on participants with motor impairments were identified.

   These results were associated with Objective 1, and were published in the paper entitled *"Assisted Interaction data analysis of web-based user studies"* (see Appendix 1).

2. The RemoTest platform proved to be useful to assist with the analysis of the data automatically collected in the experimental sessions, as well as to present accessible environments (questionnaires, task descriptions, installation process) for participants with disabilities. Based on these results, the tool was evaluated as suitable for conducting formal and inclusive experimental sessions both in remote and in situ contexts.

   These results were associated with Objective 3, and were published in two papers: *"Assisted Interaction data analysis of web-based user studies"*

(see Appendix 1) and *"Inclusive Web Empirical Studies in Remote and In-Situ Settings: A User Evaluation of the RemoTest Platform"* (see Appendix 2).

3. The tested interface adaptations with users of touch screen tablets turned out to be beneficial for most of the participants with motor impairments, mainly because navigation required less physical effort. In addition, two of the alternative interaction methods tested proved to be helpful for people with low control of finger movement.

   These results were associated with Objective 5, and were published in the paper entitled *"Adapting the web for people with upper body motor impairments using touch screen tablets"* (see Appendix 3).

4. Some improvements were suggested by participants in the experiments with touch screen tablets, including: customization features for the user interface (e.g., scrolling buttons, collapsible menus), and an adaptive system that dynamically selects the most appropriate interaction methods. These proposals were based on user tests results (both from performance and interviews with participants)

   These results were associated with Objective 6, and were published in the paper entitled *"Adapting the web for people with upper body motor impairments using touch screen tablets"* (see Appendix 3).

5. Navigation strategies of people with low vision were identified. They were used to select appropriate adaptation techniques to assist these users in web browsing.

   These results were associated with Objectives 1 and 2, and were published in the paper entitled *"An exploratory study of web adaptation techniques for people with low vision"* (see Appendix 4).

6. It was proved that the advantages of some techniques varied depending on the type of assistive technology used by participants with low vision to access the Web. For example, some of the applied adaptation techniques turned out to be helpful only for users who utilized screen magnifying software, but not for those using the browser zoom feature

   These results were associated with Objective 5, and were published in the paper entitled *"An exploratory study of web adaptation techniques for people with low vision"* (see Appendix 4).

7. Although there was no statistically significant evidence resulting from these experiments, qualitative information was obtained that guided the definition of two new research hypotheses to be validated in future work.

These results were associated with Objective 6, and were published in the paper entitled *"An exploratory study of web adaptation techniques for people with low vision"* (see Appendix 4).

8. The study performed showed that users of alternative pointing devices benefited from point and click facilitators for accessing the Web. In addition, the findings were promising in terms of performance and satisfaction achieved by participants with motor impairments. These results also suggest that the alternative pointing device used was a good indicator of how to provide better cursor assistance. In addition, improvements on performance with the use of cursor aids are predictable.

   These results were associated with Objective 5, and were published in the paper entitled *"Evaluation of two virtual cursors for assisting web access to people with motor impairments"* (see Appendix 5).

9. Significant improvements with both cursor aids compared to the original cursor in six of the seven cursor parameters studied, albeit with performance variations between some participants were supported by the longitudinal study. These results also reported an improvement in performance during the longitudinal study with one cursor aid.

   These results were associated with Objective 5, and were published in the paper entitled *"Longitudinal Study of Two Virtual Cursors for People with Motor Impairments: A Performance and Satisfaction Analysis on Web Navigation"* (see Appendix 6).

10. Suggestions for improving the area cursor, taking into account the influence on performance of distractors (i.e., nearby links to the target) were introduced. Similarly, other improvements were also suggested for the cross cursor based on performance with respect to clicking time and the opinion of participants.

    These results were associated with Objective 6, and published in the paper entitled *"Longitudinal Study of Two Virtual Cursors for People with Motor Impairments: A Performance and Satisfaction Analysis on Web Navigation"* (see Appendix 6).

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2. Conclusions

The methodology applied in this thesis has proven to be valid for improving web accessibility for different groups of users with special needs. This has been achieved through the design and development of different interface adaptation techniques and technical aids, and their subsequent evaluation with users.

The conducted user-testing has allowed us to:

(a) detect the needs of specific groups of users and compare them with the proposals to improve web accessibility found in the literature;

(b) evaluate the benefits of the developed technical aids based on different measures of performance, satisfaction and usability; and

(c) propose extensions of the technical aids to cover the more specific needs of the participating users

It is worth noting the importance of the final interviews with the participants in the different tests performed. In addition to the multiple measures analysed to evaluate the aids, very valuable information was obtained from the responses and opinions of the participants, fostering the continued improvement of the accessibility techniques by proposing new features to be implemented.

The longitudinal study carried out remotely in the participants' homes proved to be very useful and to provide categories of information that cannot be obtained with other types of studies (for instance, supervised test or single session evaluations). Among the most notable benefits that were detected, the following can be highlighted:

(a) achievement of more authentic and valuable data from unsupervised free interaction;

(b) analysis of aspects, such as the habits of use of the technical aids, in order to find out about significant issues more truthfully, such as the technology acceptance by the participants;

(c) gathering of a greater amount of participant interaction data has allowed us to analyse the significance of the results; and

(d) continuous monitoring over time, allowing us to analyse the effect of learning on the different parameters being studied (for instance, performance and satisfaction).

The technical aids developed in this thesis have proven to be beneficial in improving access to the Web for the specific groups of users with special needs for whom they were intended. The assistive technology used by the participants to access the Web (screen magnifiers, alternative pointing devices, etc.) has been a determining factor in deducing which aids were most appropriate for the user in each case. Among the various improvements proposed for inclusion in the technical aids it is worth noting the addition of different customization options gathered from the experiments with users.

The specific conclusions resulting from each of the research tasks carried out is summarized below:

- The RemoTest platform, described in Appendix 1 and Appendix 2, proved to be an exceptional tool to support experimenters carrying out user-testing. It includes features for assisting with the analysis of interaction data recorded during experiments. A straightforward visualization of each participant's interaction data in an understandable way helps experimenters to discover at a glance important issues which occurred during the experiments, and to save a great deal of time when analysing supplemental video recordings, if available. Additionally, the RemoTest also performs heuristic estimates in order to obtain measures relating to the pointer's trajectory that enable further understanding of the participants' behaviours.
- On the other hand, the RemoTest platform proved to be usable and accessible as a result of some empirical studies in remote and on-site settings (see Appendix 2). These results revealed that all the participants, regardless of their characteristics and the assistive technology they used, were able to install the tool when specific instructions were provided. The stimuli automatically generated by the RemoTest platform proved to be accessible to a wide range of users. In addition, based on comments provided by participants during the interviews, some aspects of the design were improved, such as providing shortcuts, larger text and controls, numbering the questions, using clear and simple language, etc. In addition, the user study presented in

Appendix 2 allowed us to issue a set of recommendations for the design of experiments with users with disability.

- The adaptation techniques created in this thesis were able to be embedded in other accessibility enhancing tools. For instance, some of the adaptation techniques proposed were implemented in a transcoding system (see Appendix 3). This transcoding system is able to adapt websites to touch screen mobile devices used by people with motor impairments. The evaluation showed that most users prefer transcoded pages, although a number of improvements are still required in the user interface and in the interaction methods.
- The results obtained in the exploratory study of web adaptation techniques for people with low vision (see Appendix 4), provided enriched information for selecting techniques beneficial for these users. The application of these accessibility techniques improves their experience by minimizing the number of magnification/demagnification actions needed. In addition, it makes it easier to locate navigation components and the main content of web pages as well as decreasing the number of complex actions such as horizontal scrolling.
- The cross and area cursors proposed in this thesis proved to be beneficial for participants with motor impairments. The results of the evaluation of the two cursor aids designed for assisting web access, included in Appendix 5, showed improvements in the performance of the selection of links on web interfaces. In addition, the experience showed that longer learning periods improved the user performance. These results show that people with motor impairments improve their web navigation experience if they are provided with personalized adaptations in order to assist point and click interactions.
- The quantitative results obtained from the longitudinal study of the two cursor aids proposed showed that the cross and area cursors improved the performance of both groups of participants compared to the original cursor. In addition, several improvements were designed in order to reduce the clicking time with both cursors. These results allowed us to propose other enhancements to improve the performance of the standard area cursor on web environments with closely spaced links, as can be found in Appendix 6.

2.1. Contributions

This thesis makes the following significant contributions to the field of web accessibility:

A platform for conducting formal web-based user studies has been developed. The objective was to create a tool to assist researchers to specify and conduct experimental sessions with numerous participants. This tool also collects and analyses user interaction data within the Web. The novelty of this tool is to allow user tests to be conducted both in remote and in situ contexts with the goal of analysing and detecting unusual interaction patterns of users with different impairments. This is achieved by recording the appropriate user data and by applying convenient performance and satisfaction measures. Additionally, our tool proved to be suitable for conducting inclusive experiments by presenting accessible environments for users with impairments (people with physical disabilities, blind people and people with low vision). This work was published in two peer-reviewed papers (see Appendix 1 and Appendix 2).

A new heuristic method for delimiting point and click cursor trajectories for link selection has been defined. This measurement is necessary in naturalistic experimental settings (e.g., free web navigation) in order to identify intended cursor movements as no explicit traces of the cognitive process behind the users' intention are registered. Unlike other similar heuristic methods that perform estimations based on the combined data from all individuals, the proposed one uses an individual approach (e.g., to identify valid pauses of cursor aimed movements for each individual user). This approach allows the high heterogeneity among people with disabilities to be taken into consideration. An evaluation with users with motor impairments showed that the heuristic method proposed was able to distinguish navigation patterns and determine differences between participants, for instance, in the assistive technology being used. This work was published in a peer-reviewed paper (see Appendix 1).

Additional knowledge has been provided about what difficulties are encountered by different groups of users relating to the diverse assistive technologies they use to access the Web, and how to improve accessibility through software enhancements. This knowledge derives from the formal evaluations of different technical assistances. The evaluations usually consisted of user tests with groups of people with specific disabilities. The results of this work were published in four peer-reviewed papers, corresponding to people with motor impairments using touch screen tablets (see Appendix 3), people with low vision using desktop computers (see Appendix 4), and people with physical impairments using desktop computers (see Appendix 5 and Appendix 6).

Finally, this thesis has proved that keyboard-only users with the novel cross cursor significantly improved their performance in link selection over the other options tested, as well as showing the users' preference for this new assistance. The cross cursor was designed and developed to assist web access to keyboard-only users, a group of people with motor impairments for which specific research in this area was barely found. The results also revealed a positive learning effect, with better performances being achieved with frequent use over time. These results were obtained from two experiments (a preliminary single-session test and

a longitudinal test) performed to compare the cross cursor with other cursor variants. Users of different alternative pointing devices participated in these experiments. This work was published in two peer-reviewed papers (see Appendix 5 and Appendix 6).

As a result of this thesis work, we were invited to publish part of the knowledge built in a book chapter. The prestigious De Gruyter international publishing house included the following peer-reviewed chapter in the book entitled *"Personalized Human-Computer Interaction"*:

- JULIO ABASCAL, OLATZ ARBELAITZ, XABIER GARDEAZABAL, JAVIER MUGUERZA, J. EDUARDO PÉREZ, XABIER VALENCIA, AND AINHOA YERA, ''Personalizing the user interface for people with disabilities,'' in *Personalized Human-Computer Interaction*, M. Augstein, E. Herder, and W. Wörndl, Eds. Berlin, Germany: De Gruyter, 2019, ch. 10, pp. 253–282.

2.2. Future work

With regard to the various software developments resulting from this work, which include the multiple technical aids and the platform for conducting user studies, the next step is to develop downloadable versions of these programs for end users. According to the distributed architecture we have followed to collect and analyse user interaction, a broader amount of participants would become available this way, which in turn would allow us to continue studying behavioural patterns and to improve technical aids.

The target users of this thesis were people with physical impairments and people with visual restrictions. With them, we tested technical aids to allow access to desktop computers and touch screen tablets. For the future, we plan to extend this work, applying the same methodology to other types of users, for example, people with cognitive impairments, and to other devices, for example, smartphones, smartwatches, etc.

In this thesis, various interface adaptations were tested through a transcoding system. This system was supported by an annotation procedure that provides the necessary additional semantic information to the html content. The workload for manual annotation of web pages is a major drawback of this approach. Therefore, we plan to investigate alternatives, such as crowdsourcing or gamification techniques, to speed up the annotation process.

In order to broaden the availability of verified software enhancements for assisting the access to Web interfaces we plan to perform further research on

other interactions than point and click for link selection. For instance, opening dropdown menus of navigation bars, filling forms with diverse elements, or interacting with new dynamic content.