A Framework for Performance Evaluation of Internet Assistive Tools for Blind Users

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Abstract—There exist several accessibility evaluation tools for websites. However, no formal framework is available to evaluate the performance of assistive tools that are used by blind users to use internet. In this paper, we present a hierarchical model for quantitative evaluation of assistive tools for blinds. Identifying various performance attributes and Design metrics, we establish relationship among these to obtain the overall performance Index of the assistive tools. It is hoped that researchers and the others concerned shall find the work relevant for further discussion and formalization in this direction.

Keywords— Assistive Tools, Screen Readers, Performance attributes, Speech based Browsers, Accessibility, Usability, Navigability.

I. INTRODUCTION

During recent years, many speech-based assistive web browsers for blind users have emerged in both free domains as well as on proprietary basis. There exist several frameworks for accessibility evaluation for WebPages and websites. However, to the best of knowledge of authors, as long as no formal framework is available in literatures that could be used to evaluate performance of the assistive tools in quantitative terms. Perhaps the difficulty in quantifying various decisive quality parameter, establishing relationships among these parameters and more importantly, determining their values from standard test cases have prevented from formalization of a performance evaluation framework.

The W3C's Web Accessibility Initiative (WAI) [1,2] has been the major force in providing standards, guidelines and awareness related to the web accessibility. The Web Content Accessibility Guidelines (WCAG) [3], User Agent Accessibility Guidelines (UAAG) [4], Authoring Tool Accessibility Guidelines (ATAG) [5] are of particular relevance. The UAAG considers the accessibility of Web User Agents i.e. Web Browsers, Assistive tools, Multimedia access tools etc. The currently stable version of the User Agent Accessibility Guidelines is the UAAG 1.0, published in 2002[4] The purpose of the UAAG 1.0 is to provide guidelines for designing accessible Web user agents. UAAG 1.0 introduces 12 guidelines, associated with checkpoints of three priorities and three conformance levels: A (lowest), AA, and AAA (highest). Informative resources about different techniques are also available. In addition, the UAAG 1.0 defines a system called conformance profile labels. This supports developing and documenting (specialized) user agents that conform only to a subset of all conceivable accessibility features.. Although UAAG 1.0 provided valuable notes to the user agent developers, it cannot be relied since the usage of UAAG-conformant browsing technology cannot guarantee to produce WCAG conformant web content [6, 7]. The problem with UAAG 1.0 is that it does not consider the actual performance of the tool for user but categorizes a tool on the basis of features provided therein

In this paper, we present a framework which comprehensively encompasses all important performance attributes of speech based web access systems for blind users irrespective of approaches used therein. On the basis of these performance attributes, we try to establish a quantitative relationship among these to obtain the overall performance index for the assistive tool for blind users.

II. PROBLEMS AND ISSUES

A. *Accessibility, Usability and Navigability*

Accessibility, Usability and Navigability are the terms that creates lot confusion and are frequently encountered in related literature. Therefore, it is important to unambiguously define them before proceeding further. Each is a tripartite [8] as it relates the three aspects: Web Page(s), Assistive tool and Blind User. This fact is depicted in Figure 1. These properties are defined in Table 1 from the aspect of each player concerned.

The first role to ensure accessibility, usability and navigability in webpage(s) lies with Web Authors who are expected to follow the accessibility guidelines during website creation. Assistive tools can, most often function correctly if the webpage is compliant to the accessibility guideline. Unfortunately, this is not always the case since a large percentage of web pages have inaccessible contents. Thus, the role of assistive tools becomes important in terms of enhancing accessibility, usability and navigability of the webpage(s) so that blind users may be able to access and use them. However, they are required to become proficient in using the assistive tool as well as to find out tricks and ways to use the web against all odds. Thus, they also have to play a role to efficiently use the assistive tool.

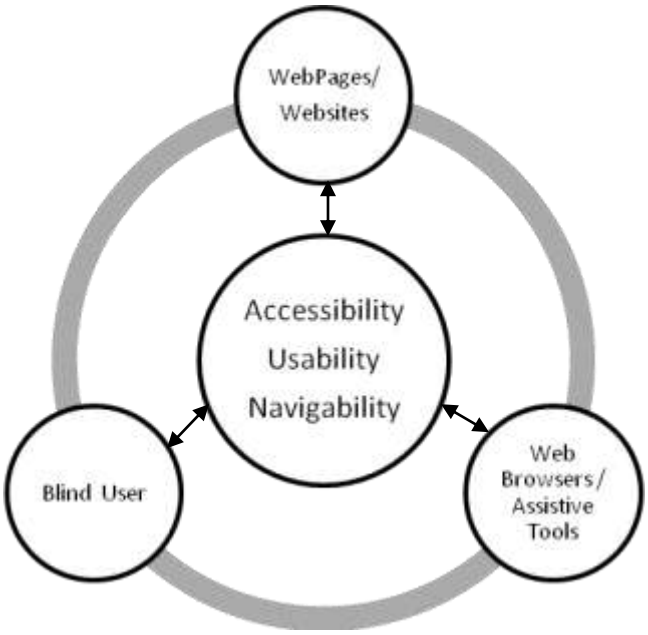

Fig. 1 The three aspects of Accessibility, Usability and Navigability

Table 1 Accessibility, Usability and Navigability defined from the three perspectives

Property	Web Page(s)/ Web Author Perspective	Assistive Tools/Service Perspective	Blind User Perspective
Accessibility	The property of webpage(s) by virtue of which each element of it can be traversed by blind user using keyboard only.	The amount by which an assistive tool enhances the ability of a blind user to access each element of a web page using keyboard only.	The ability to access each element of a web page by blind user using keyboard only.
Usability	The property of webpage(s) by virtue of it a blind user can perform the tasks offered by webpage(s) independently.	The amount by which an assistive tool enhances the ability of a blind user to perform the tasks offered by webpage(s) independently.	The ability of a blind user to perform the tasks offered by webpage(s) independently
Navigability	The property of webpage(s) by virtue of it blind user can navigate around intra/ inter page links efficiently to access/ use its features.	The amount by which an assistive tool enhances the ability of a blind user to navigate around intra / inter page links efficiently to access/ use its features.	The ability of user to navigate around intra/ inter page links efficiently to access/ use its features.

B. Various Categories of Web Usage by Blind Users

Web usage by a blind user may be categorized into simple, intermediate and complex. A usage is simple if a blind user browses for some news article, e-book or collects information on some topic. Screen Readers may serve well for all such simple usages. Tasks like sending or receiving e-mails, performing simple queries like finding examination result of a student by entering his/her roll number may be considered as of intermediate complexity. Tasks like getting a travel ticket reserved or performing online bank transaction are of complex category because they require multiple form filling that may spread across several web pages in a complex structure.

C. Various strategies to design the Web Accessibility tools for Blind Users

Several strategies are used to address the issues related to speech based web access for blind users. The first strategy employs a client based assistive tool (e.g. screen reader) to speak out the web content in some desired order. Generally, such tools are required to be installed locally on user computer. Second strategy makes the use of a proxy server or client based transcoder [9] that renders the web content after converting it to a more accessible form. Another strategy used is to speech enable a website directly by the web author thus requiring no assistive tool on part of blind user. None of these strategies provide perfect solution for the problem and each may have its own merit and drawback. Usability of the screen readers is mainly constrained by the complex structure/ poor accessibility of web pages. The transcoder based access services may not be applied for secure sites as they do not permit to access or modify its code by a third party. Direct Speech enabling a site may be difficult to maintain.

D. Universal Vs. Local Installation

An assistive tool may require to be locally installed on user machine or it may be provided online as a web service. The first approach constraints the use of the assistive tool by its availability in installed form whereas in the second approach local installation is not required. Thus, user can access the web using any public terminal.

E. Role of Assistive Tools

Various assistive tools for using web by blind users have been designed using approaches like context based approach, semantic approach, annotation based approach, text summarization, etc. These assistive tools try to enhance the power of blind user by performing one or more of the following changes:

-Provide TTS (Text to speech) service i.e. speaking out the content of web page and giving speech feedback to user input by echoing the character typed. (basic service).
-Make the search informed using some heuristics, thereby reducing the time taken to search some information on web page.

- Providing better control over web page element by the means of shortcut keys,

- Take to some otherwise inaccessible content.

- Take to some otherwise unreachable link / form element

-Reduce the no of links (Performances) required to traverse to reach to some element on web page.

-Simplify the webpage both in structure and content.

- Providing a better understanding of web page layout / structure.

- Providing a better understanding of images by the means of reading out their ALT text.

- Providing a better understanding of visual diagrams by interpreting them.

III. DEFINING THE FRAMEWORK

From the previous section, it is clear that despite diverse approaches being used, the assistive tools have a common goal of enhance in accessibility and usability of web pages for blind users. Thus, it is legitimate to assess their performance on the basis of the common objective fulfillment.

Methodology used in the development of model proposed in this paper is based on a hierarchical model for assessment of quality of object oriented design based software [10]. A general schematic for the performance evaluation of an assistive tool has been shown in the Fig. 2. Attributes in higher order of hierarchy affect the overall performance however; it may be difficult to measure them. Thus, we have to move down in hierarchy to get lower order attributes which can be measured through a well defined set of metrics.

A. Identification of Performance Attributes

Based on the data available from the literature, attributes like HCI Index, User Satisfaction Index, User Frustration Index, Quality of Life Index, Simplification Index and Tool Effectiveness Index were were taken as the set of Performance attributes in the model. These attributes affect the overall browsing experience thus are major performance indicators. Table 2 summarizes the Performance Attributes with their roles in performance of assistive tool.

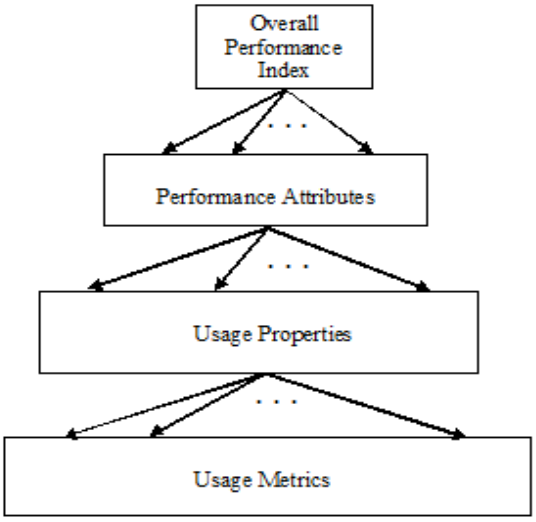

Fig. 2: Schematic Hierarchical Structure

Table 2 Performance Attribute Definitions

Sr. No.	Performance Attribute	Performance Attribute Definition
1	**HCI Index**	A measure of the extent to which the user interaction with computer is enhanced in comparison to the ground level. It allows the user to comfortably use the assistive tool. It reflects user's control over use of computer.
2	**User Satisfaction Index**	Reflects the enhancement in user satisfaction level due to the use of the assistive tool in compare to the ground level. It is evident from user applaud for the tool.
3	**User Frustration Index**	Reflects the reduction in the instances of user's frustration[11] while using the assistive tool in comparison to the ground level.
4	**Quality of Life Index**	Reflects the gains occurred in the life of blind user and improvement in the ability of a blind in terms of performing tasks independently.
5	**Simplification Index**	Reflects the extent to which page structure and contents are simplified by the tool.
6	**Tool Effectiveness Index**	Refers to the assistive tool's ability to achieve the desired functionality and behavior.

B. Identification of Usage Properties

A Usage attribute represents an aspect that may affect the performance of assistive tool. We have identified eight Usage Properties that affect the performance attribute in some way or other. The definition of these properties is given in Table 3.

Table 3 Usage Property Definitions

Sr. No.	Usage Property	Usage Property Definition
1	**Accessibility**	Indicates the reduction in no. of unreachable elements in webpage by the use of assistive tool as compare to that in the ground value.
2	**Usability**	Indicates reduction in difficulty in the use of website. It is denoted by the increase in no of tasks performed from the ground case.
3	**Navigability**	Indicates the capability to navigate around intra/ inter page links efficiently to access/ use its features..
4	**Element Processing Time**	Indicates the reduction in average time spent on processing the page elements (nodes) to perform a task using form filling..
5	**No. of Probes**	Indicates the reduction in average no. of probes [12] required by a blind user after using the assistive tool as compare to the ground case.
6	**Page Layout Understandability**	Indicates the enhancement in blind user's ability to understand the page layout simplified by assistive tool as compare to the ground case.
7	**Page Context Understandability**	Indicates the enhancement in blind user's ability to make an overview of the page context [7] as compare to the ground case.
8	**Rich Internet Applications (RIA)**	Indicates the enhancement in blind user's ability to understand the RIA content as

	Understandability	compare to the ground case.[13,14]

C. *Identification of Usage Metrics*

Each of the Usage property described in Table 4 corresponds to a metric value that is obtained by applying the assistive tool on test case WebPages. The complete suite of Usage Metrics for the proposed model is described in table 5.

Table 4 Usage Metrics Descriptions

Sr. No.	Name of the Metric	Metrics Description
1	**Accessibility Metric**	No. of page elements that can be accessed using keyboard only.
2	**Usability Metric**	No. of tasks that can be performed on a web page.
3	**Navigability Metric**	Average no of navigations (Performances) required to access an element on a web page.
4	**Time to Process Nodes Metric**	Average time spent on an element during form fill to perform a task.
5	**probes Metric**	Number of probes required on a web page.
6	**Structural Assessment Metric**	Time required for assessing the layout of a webpage.
7	**Context Assessment Metric**	Time required for assessing an context/ overview of a webpage.
8	**Rich Content Metrics**	Number of rich content elements that can be accessed on a web page.

D. *Ground Case Values of Usage Metrics*

Ground case values of Usage Metrics are obtained when a blind user uses a plain Text To Speech (TTS) to surf the webpage using link navigation through Tab key presses only.

Each of the Usage Property is calculated from the Usage Metric using the following relation:

$$UP = \frac{|(UM)_{AT} - (UM)_{GROUND}|}{UM}$$

Where UP is the Usage Property, $(UM)_{AT}$ is the Usage Metric value for blind user using assistive tool. $(UM)_{GROUND}$ is the Usage Metric value for blind user in ground case. UM is the corresponding Usage Metric value for sighted user.

E. *Mapping Usage Properties to Performance Attributes*

Each Performance Attributes is determined by some of the usage Properties. The table 5 shows the influence of each of the Usage Property on the Performance attributes. An up arrow symbol (↑) indicates that the Usage Metric has positive influence on the Performance Attribute and the down arrow symbol (↓) indicates that the Usage Metric has negative influence on the Performance Attribute.

F. *Formulation for Performance Attributes*

For preparation of formulation for Performance Attributes in terms of the Usage Properties, the relative significance of Usage Properties that influence a Performance Attribute has to be weighted proportionally so that the computed values of all Performance Attributes have the same range. A range of 0 to +1 or –1 is selected for the computed values of the Performance Attributes.

Because actual metric values of different ranges are combined in the computation of the Performance Attribute indices, the metric values have to be also normalized. These normalized values of the Usage Metrics are to be then used for computation of the Performance attribute values as per the formulation shown in table 6.

G. *Formulation for Overall Performance Measure of Assistive Tool*

Formulation of the overall performance Index of the assistive tool in terms of the Performance attribute values will be based on the relative influence of these attributes on the overall performance of the Assistive Tool. This influence can be determined by aggregating the opinion taken from some specified number of experts. The equation for calculating Overall Performance Index from the Performance attribute values is given in table 7. Factor values of C1 to C6 are chosen such that their sum is 1. The values can be set by expert opinion only after considering all the factors discussed previously in section II subsections B, C and D.

Table 5 Mapping of Usage Properties to Performance Attributes

	HCI Index	User Satisfaction Index	User Frustration Index	Quality of Life Index	Simplification Index	Tool Effectiveness Index
Accessibility		↑	↓	↑		↑
Usability		↑	↓	↑		↑
Navigability	↑	↑	↓	↑		
Element Processing Time	↓		↑			↓
No. of Probes	↓		↑			↓
Page Layout Understandability	↑	↑			↑	↑
Page Context Understandability		↑	↓	↑	↑	
Rich Content Metrics		↑		↑		↑

Table 6 Formulation for the Performance Attributes

Performance Attribute	Formulation for Index Computation
HCI Index	0.75* Navigability +0.75*Page Layout Understandability - 0.25*Element Processing Time-0.25* Number of Probes
User Satisfaction Index	0.10* Accessibility+ 0.20* Usability +0.10* Navigability +0.20*Page Layout Understandability +0.20* Rich Content Metrics +0.20* Page Content Understandability
User Frustration Index	-0.5 * Accessibility- 0.5 * Usability -0.5 * Navigability + 0.5*Element Processing Time-0.5 * Page Content Understandability+0.5* Number of Probes
Quality of Life Index	0.20* Accessibility+ 0.20* Usability + 0.20* Navigability + 0.20* Page Content Understandability+0.20* Rich Content Metrics
Simplification Index	0.5*Page Layout Understandability + 0.5 * Page Content Understandability
Tool Effectiveness Index	0.5* Accessibility+ 0.5* Usability +0.5*Page Layout Understandability +0.5* Rich Content Metrics-0.5* Number of Probes - 0.5*Element Processing Time

Table 7 Equation for Overall Performance Measure

Overall Performance Index = C1* HCI Index + C2 * User Satisfaction Index + C3 * User Frustration Index + C4 * Quality of Life Index + C5 * Simplification Index + C6 * Tool Effectiveness Index

IV. Using the Framework in Performance Evaluation

To use the framework for performance evaluation of assistive tools, following are the desirables:

1. Automated tools to assess the webpage metrics,
2. Benchmark Test cases chosen from each category of webpage defined earlier in section II subsection *B.* ,
3. A predefined no. of sighted and blind users to run test cases.
4. A predefined no. of experts to Design and run test cases.

It is worth mention that rich work is available related to the accessibility and usability testing of websites [12, 15, 16]. In most cases, the work can be extended for the evaluation of assistive tools.

V. Results and Discussions

In this paper, we have tried to formulate a hierarchical framework to evaluate the performance of assistive tools for blind users through carefully chosen performance attributes and indicators. The task was difficult due to lack of related previous work. Specifically, our contributions in this paper include:

1. Identification of a ground case that is taken as reference benchmark to evaluate the assistive tools for blinds,
2. Defining the Performance Attributes for assistive tools.
3. Defining Usage properties for assistive tools,
4. Defining the Usage Metrics that are affected by an assistive tool,
5. Establishing relationships between Usage Properties and Performance Attributes thereby getting the overall performance index for the assistive tool for blinds.

Although the framework may further require being refined and fine-tuned, it may be the basis for the selection of an assistive tool for blinds.

VI. Conclusions and Future Directions

It has been common practice to identify a web assistive tool by its distinctive feature or approach e.g. context driven, semantic driven, Annotation based etc. Whatever approach, methodology or strategy used therein, their objective is single: empowering the blind users for what their counterpart sighted users enjoy naturally in day-to-day life. Thus, it is legitimate to formulate the performance evaluation criteria for assistive tools despite several hindrances like diversity in architecture and methodologies, approaches, testability due to lack of well defined benchmark test cases etc. It is expected that these and other issues shall be taken up with priority by the concerned researchers, interest groups and formal bodies in near future.

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