Fuzzy linguistic ranking model for Web Accessibility Test tools

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Abstract—There are dozens of tools to automatically evaluate web accessibility. Some are online, and some are toolbars to complement web browsers. In order to select the best Web Accessibility Test Tool, various aspects should be considered. Among the various aspects, the evaluation environment has an important role to assume in the evaluation criteria of the website. The ability to evaluate websites that require user permissions or they are freely accessible could affect the accessibility outcome due to limited or no access to the tool. In addition, the interpretability of the results differs from one tool to another, and it can be difficult to identify the areas of opportunity for improvement of the website evaluated. To select the best tool that matches experts’ needs, it is important to have a group of experts in the area. These experts will give their opinions on the criteria according to which the tools will be evaluated. Each Web Accessibility Test Tool is an alternative in a decision making problem (DM). A DM which is evaluated by a group of experts is called a Multi-Expert Multi-Criteria (MEMC). Contrary to studies where the assessments are quantitative, this research uses Computing with Words (CW) processes. Because experts may have uncertainty at the time of issuing their evaluation, Intuitionistic Fuzzy Sets (IFS) are used to work with that uncertainty. Finally, a ranking of the evaluated tools is carried out by TOPSIS.

Keywords—Intuitionistic Fuzzy Set (IFS), TOPSIS, Multi-Expert Multi-Criteria Linguistic Decision Making (MEMCLDM), Web Accessibility Tools Test, Ranking.

I. INTRODUCTION

The World Wide Web Consortium (W3C) is an international community working towards international standards for the web. W3C dictates a series of standards –WCAG 1.0 1 in 1999 and WCAG 2.0 2 in 2008– to make web information accessible to everyone regardless of hardware, software, network infrastructure, language, culture, geographic location, or physical or mental ability. Currently there are several tools that evaluate the accessibility of websites automatically. The tools contain different features that may or may not facilitate the evaluation of the site depending on the context in which they are applied. Choosing the right tool for the expert’s needs is a decision making problem (DM). A DM is a typical problem that has different alternatives to choose from valued by experts in the topic.

In this document, a fuzzy linguistic model is proposed for evaluating accessibility tools through nine criteria: (1) Learnability, (2) Scope of application, (3) Displays element evaluation,ig (4) Accessibility level, (5) Accuracy, (6) CSS evaluation, (7) Reports, (8) Intuitivity, (9) Standardized output. Commonly, the valuation process is done using numerical scales. This research makes use of enhanced linguistic terms in order to take advantage of the knowledge and experience of the experts in a better way, since the evaluation is performed using natural language. The decision-making process is carried out by intuitionistic linguistic representation using linguistic sets in the expert opinions on the criteria to be evaluated of the accessibility tools. Finally, using TOPSIS, the results are aggregated to rank the tools evaluated.

This document is structured as follows: Section II provides a descriptive summary of the preliminaries relating to the Intuitionist linguistic model as well as TOPSIS as a technique for the ranking of alternatives. In Section III, we present a Fuzzy linguistic ranking model. In Section IV, we apply a ranking model for Web Accessibility Test tools. Finally, in Section V, the conclusions are presented.

II. PRELIMINARIES

This section describes the methodologies applied to the Multi-Expert Multi-Criteria Linguistic Decision Making (MEMCLDM) problem for ranking in the alternative selection.

A. Multi Criteria Decision Making

The Multi-Criteria Decision Making (MCDM) was introduced in the early 1970s. It is a tool used for problem assessment and decision making with multiple alternatives that are evaluated considering multiple criteria [1], [2].

MCDM often deal with different types of problems such as selection, ranking and classification problems. The aim on each kind of problem is different: (1) selection problems is expected to find the best alternative; (2) the ranking problems are aimed at determining the suitability of all alternatives, which is presented as a hierarchy from the best to the worst and (3) in the classification problems we want to know which alternatives belong to which class of a predefined set of ordered classes.

There are several methods of solving MCDM problems that are used to form a ranking of alternatives. The TOPSIS method [3] is one of them. TOPSIS is based on an aggregation function

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1https://www.w3.org/TR/WAI-WEBCONTENT/
2https://www.w3.org/TR/WCAG20/
of the experts’ evaluation scores and determines the best alternative by calculating the distances between the positive and negative ideal solution.

MCDM problems can be evaluated by various experts to be approached as MEMCLDM problems. These experts are usually people with experience in the subject to be assessed. Alternatives can be assessed quantitatively or qualitatively. To evaluate qualitative information, the use of the Fuzzy Set Theory (FST) [4], proposed by Zadeh in 1965, has been very successful. In order to achieve an efficient evaluation of the perception of the experts, the use of linguistic variables[5] and the procedures of Computation with Words (CW) [6], [7] are used in intelligent computer systems [8], [9], [10], [11].

B. Intuitionistic fuzzy representation model

Intuitionistic Fuzzy Set (IFS) was proposed by Atanassov in 1986. IFS [12] is characterized by having simultaneously a membership and a non-membership with a degree of hesitance. The IFS are models of information representation used to support decision making and are very useful because of the ability to express imprecise or uncertain information more flexibly than the traditional fuzzy sets [2], [13].

According to Atanassov [12] an IFS A, in the universe \( X = \{x_1, x_2, \ldots, x_n\} \), it is represented as:

\[
\tilde{A} = (x_j, \mu_\tilde{A}(x_j), \nu_\tilde{A}(x_j)) \mid x_j \in X
\]

where \( \mu_\tilde{A}(x_j) \in [0,1] \) and \( \nu_\tilde{A}(x_j) \in [0,1] \) represents respectively the membership and the non-membership degrees of the element \( x_j \). Then an IFS has the following requirement:

\[
0 \leq \mu_\tilde{A}(x_j) + \nu_\tilde{A}(x_j) \leq 1
\]

The function \( \pi_\tilde{A}(x_j) \) represents the degree of hesitancy of \( x_j \) and it is defined as:

\[
\pi_\tilde{A}(x_j) = 1 - \mu_\tilde{A}(x_j) - \nu_\tilde{A}(x_j)
\]

Let \( \alpha \) and \( \beta \) be two intuitionistic fuzzy sets, \( \lambda \) be a number. Hence, the main algebraic operations of any two intuitionistic fuzzy sets \( \alpha = (\mu_\alpha, \nu_\alpha) \) and \( \beta = (\mu_\beta, \nu_\beta) \) can be defined in the following way [14] and [15]:

1) Addition \( \oplus \):

\[
\alpha \oplus \beta = (\mu_\alpha + \mu_\beta - \mu_\alpha \mu_\beta, \nu_\alpha + \nu_\beta)
\]

2) Product \( \otimes \):

\[
\alpha \otimes \beta = (\mu_\alpha \mu_\beta, \nu_\alpha + \nu_\beta - \nu_\alpha \nu_\beta)
\]

3) Scalar product:

\[
\lambda \alpha = (1 - (1 - \mu_\alpha)^\lambda, \nu_\alpha^\lambda), \lambda > 0;
\]

4) Scalar power:

\[
\alpha^\lambda = (\mu_\alpha^\lambda, 1 - (1 - \nu_\alpha)^\lambda), \lambda > 0.
\]

The Intuitionistic Fuzzy Weighted Average (IFWA) aggregation operator was initially proposed by [15], it has been used to aggregate the individual opinions of decision makers [16], [17]. Let \( R^{(k)} = (r_{ij}^{(k)})_{m \times n} \) be an intuitionist decision-making matrix with the evaluations of each alternative \( A_i \) with \( (i = 1, \ldots, m) \) and criterion \( C_j \) with \( (j = 1, \ldots, n) \) by each decision maker \( D M_k \) with \( (k = 1, \ldots, d) \). Let \( w_k \) be the weight of each decision maker \( D M_k \) where \( \sum_{k=1}^{d} w_k = 1 \). Then the final result of applying the IFWA aggregation operator is an IFS value given by Eq.(5):

\[
IFWA_w = IFWA_{w1} = \begin{bmatrix} w_1 r_{ij}^{(1)} + w_2 r_{ij}^{(2)} + \cdots + w_d r_{ij}^{(d)} \end{bmatrix} = [\chi, \psi, \delta]
\]

where

\[
\chi = 1 - \Pi_{k=1}^{d} (1 - \mu_{ij}^{(k)}) w_k
\]

\[
\psi = \Pi_{k=1}^{d} (\nu_{ij}^{(k)}) w_k
\]

\[
\delta = \Pi_{k=1}^{d} (1 - \mu_{ij}^{(k)}) w_k - \Pi_{k=1}^{d} (\nu_{ij}^{(k)}) w_k.
\]

Intuitionistic fuzzy representation has been widely used with multicriteria decision-making techniques [18] such as Intuitionistic fuzzy TOPSIS [17], Intuitionistic fuzzy AHP [19], Intuitionistic fuzzy VIKOR [20], Intuitionistic fuzzy ELECTRE [21], among others, with the purpose of order the alternatives.

C. Intuitionistic fuzzy TOPSIS

There are different techniques for the ranking of alternatives in MEMCLDM. TOPSIS is a technique which uses the order by similarity with an ideal solution [3]. TOPSIS is based on the fact that the alternative selected must be the one that contains the closest distance from the ideal solution and the furthest distance from the negative solution. The Fuzzy TOPSIS technique is widely applied in decision making [22] and it is considered as one of the best MCDM methods to solve problems. Due to its simplicity of application avoiding it application in alternatives ranking when a new alternative is inserted [23]. Boran et al. [16] proposes the Intuitionistic fuzzy TOPSIS to be applied following these steps:

1) Let \( W_j = (\mu_j, \nu_j) \) be the intuitionistic fuzzy weight of each criteria \( C_j \) according to alternative \( A_i \). Let \( R' = (r'_{ij})_{m \times n} \) be the matrix of the aggregated intuitionistic fuzz sets with \( m \) alternatives and \( n \) criteria. Then the weighted normalized matrix is calculated by Eq.(6) and Eq.(7).

\[
R' \otimes W_i = \{ (\mu_{i_j} \mu_{W_j}, \nu_{i_j} + \nu_{W_j} - \nu_{i_j} \nu_{W_j}) \mid r'_{ij} \in R' \}
\]

\[
\pi_{ij} = (1 - \nu_{i_j} - \nu_{W_j} - \mu_{i_j} \mu_{W_j} + \nu_{i_j} \nu_{W_j})
\]

2) The positive intuitionistic fuzzy ideal solution vector \( A^+ \) can be determined as:

\[
A^+ = (\mu_A - W_j, \nu_A + W_j)
\]

Where \( \mu_A \) and \( \nu_A \) are known as positive and negative ideal alternative, respectively.
C. Exploitation phase

The negative intuitionistic fuzzy ideal solution can be determined as:

\[ A^- = (\mu_{A^-} - W_j, \nu_{A^-} - W_j) \]  

where

\[ \mu_{A^-} - W_j = \min_i \mu_{r_i} - W_j \]
\[ \nu_{A^-} - W_j = \max_i \nu_{r_i} - W_j. \]

4) Calculate the distance measurement, using the Euclidean distance. The separation of each alternative from the ideal solution is given as:

\[ S_i^+ = \frac{1}{2} \sum^m_{j=1} \left[ (\mu_{r_i} - W_j - \mu_{A^-} - W_j)^2 + (\nu_{r_i} - W_j - \nu_{A^-} - W_j)^2 \right]. \]

5) Similarly, the separation of the negative solution is given as:

\[ S_i^- = \frac{1}{2} \sum^m_{j=1} \left[ (\mu_{r_i} - W_j - \mu_{A^-} - W_j)^2 + (\nu_{r_i} - W_j - \nu_{A^-} - W_j)^2 \right]. \]

6) Then rank the order of preference by the relative proximity coefficient as:

\[ RPA_i = \frac{S_i^+}{S_i^+ + S_i^-}. \]

IV. A RANKING MODEL FOR WEB ACCESSIBILITY TEST TOOLS

It is desired to evaluate the level of accessibility of a web system. There are several tools supported by the World Wide Web Consortium (W3C) with different features. The DM set limits the main set to the six tools commonly used among them. The set of Web Accessibility Test (WAT) tools are evaluated in relation to a set of nine criteria. It must be decided which of this set of six tools is best suited to your needs. The tools considered are the following:

1) Wave³ (c1),
2) Achecher⁴ (c2),
3) eXaminer⁵ (c3),
4) AccessMonitor⁶ (c4),
5) Accessibility Check³ (c5),
6) TAW⁸ (c6).

A. Representation phase

The first phase consists of the definition of Linguistic Terms Set (LTS) that will be used for decision making. Decision makers denoted as \( DM_k \) with \( k = 1, \ldots, d \). Should be select a set of diversity \( DM \) that have experience and knowledge directly related to the problem to evaluate the available alternatives. The set of alternatives \( A_i \) with \( i = 1, \ldots, m \) are evaluated using a set of criteria \( C_j \) with \( j = 1, \ldots, n \).
Table (II) were used by a coordinator to define the weight \( W_j \) of each criteria \( C_j \), as presented in Table (III). Also, using Table (II), each \( DM_k \) evaluates the performance of each alternative in each criterion. Table (IV) presents decision makers assessments.

### B. Aggregation phase

Once the individual matrix of intuitionistic evaluations has been obtained, the matrix must be aggregated using the IFWA operator presented in Eq. (5). In this study-case, the weight of the decision makers were considered the same. The IFWA operator is used to aggregate them into a group decision making matrix. The aggregation results are presented in Table (V). Due to the space, only two assessments are displayed. Next, a weighting process of the group decision matrix (V). Due to the space, only two assessments are displayed. Making matrix. The aggregation results are presented in Table (VI).

### C. Exploitation phase

In this step, the performance of each alternative should be calculated using the distance measurement from Fuzzy TOPSIS technique. The intuitionistic fuzzy ideal positive and negative solution are founded using Eq. (8) and Eq. (9). The distance between each aggregate weighted evaluation of the alternatives’ results and the intuitionistic fuzzy ideal positive and negative solution is calculated using the Eq. (10) and Eq. (11). The results are presented by Table (VIII) and Table (IX) respectively.

Finally, the alternatives are ordered by relative proximity as in Eq. (12). The resulting order is presented in Table (X) with \( a_1 > a_2 > a_6 > a_5 > a_3 > a_4 \). Alternative \( a_1 \) is selected as the best tool with the best scores in 6 of 9 criteria evaluated. The selected tool can be highlight as very intuitive, since it marks errors and warnings in the html label, due this, it is easy to identify where are the errors.

### V. Conclusion

This study proposed and tested a Multi-Expert Multi-Criteria Decision model in order to evaluate and select Web Accessibility Test tools that combines the Intuitionistic fuzzy representation and the TOPSIS technique. It fulfills several important characteristics for a decision making process:

- The use of linguistics variables instead of numerical scales enhances the assessment of alternatives in decision-making problems because the cognitive processes of human beings accept words rather than numbers;
- The use of Intuitionistic Fuzzy Set (ISF) is used due to the imprecision found in the parameterization since there may be a degree of hesitation. IFS takes into account the degree of membership, degree of non-membership and hesitancy;
- Finally, being able to rank the alternatives with fuzzy information allows a better interpretability of results for decision makers.

The Wave tool resulted best valued in comparison with five tools. Wave is considered an easy learning tool, the plug-in installation to the browser is very simple. Wave has a high degree of intuitiveness and as a toolbar, it allows the evaluation of websites with the users’ permissions. The assessment is displayed on each element evaluated, enabling rapid identification of errors and warnings. Experts rank the Wave tool first, considering the set of criteria. As a further research, it is suggested to explore other techniques in combination with linguistic fuzzy representations and compare their results with the proposal presented in this study.

### ACKNOWLEDGMENT

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### REFERENCES

### Table IV: Valuations of $d = 7$ Decision makers for $m = 6$ alternatives according to $n = 9$ criteria

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### Table V: Aggregation Matrix of $a_1$ and $a_2$

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### Table VI: Weighted Aggregation Matrix for $a_1$ and $a_2$

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### Table VII: Ideal intuitionistic fuzzy positive and negative solutions.

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TABLE IX

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</tr>
</tbody>
</table>

TABLE X

<table>
<thead>
<tr>
<th>Solution</th>
<th>( S^+ )</th>
<th>( S^- )</th>
<th>( \text{RP}_{33} )</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_1 )</td>
<td>0.162</td>
<td>0.287</td>
<td>0.822</td>
<td>4</td>
</tr>
<tr>
<td>( a_2 )</td>
<td>0.118</td>
<td>0.250</td>
<td>0.694</td>
<td>2</td>
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<tr>
<td>( a_3 )</td>
<td>0.185</td>
<td>0.197</td>
<td>0.516</td>
<td>5</td>
</tr>
<tr>
<td>( a_4 )</td>
<td>0.303</td>
<td>0.042</td>
<td>0.122</td>
<td>6</td>
</tr>
<tr>
<td>( a_5 )</td>
<td>0.175</td>
<td>0.192</td>
<td>0.523</td>
<td>4</td>
</tr>
<tr>
<td>( a_6 )</td>
<td>0.115</td>
<td>0.253</td>
<td>0.689</td>
<td>3</td>
</tr>
</tbody>
</table>