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# Robot Arm Utilized Having Meal Support System Based on Computer Input by Human Eyes Only

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**Abstract**

A robot arm utilized having meal support system based on computer input by human eyes only is proposed. The proposed system is developed for handicap/disabled persons as well as elderly persons and tested with able persons with several shapes and size of eyes under a variety of illumination conditions. The test results with normal persons show the proposed system does work well for selection of the desired foods and for retrieve the foods as appropriate as users' requirements. It is found that the proposed system is 21% much faster than the manually controlled robotics.

**Keywords:** Computer Input by Human Eyes Only, Line of Sight Estimation, Gaze Estimation, Robot Arm control, Image Segmentation With Clustering.

## 1. INTRODUCTION

There are some systems which allow computer input by human eyes only [1]. Just by sight, any desired key can be selected and determined with the system composed with a camera mounted computer display and the methods for gaze estimation with the acquired user face images [2]. The system allows users' head movements using head pose estimation by using extracted feature points from the acquired face images and also estimate line of sight vector which defined a s the line which connects between pupil center and eyeball center [3]. Thus computer input by human eyes only can be done.

There are 2.1 million of handicap persons (about 6%) in Japan. They can use their eyes; they cannot use their body below their neck though. By using the computer input system by human eyes only, they can take a meal through a selection of foods of which they want to have if they guide the robot arm by their eyes only. Using the system, users can control robot arms then users can bring foods of which they would like to have by their own choice. The current system allows to support having meal by retrieving not too hot drinkable foods and drinks with tube because it is not easy to feed the foods with folk (it is dangerous to get close the folk to user's face) for disable persons.

There are some meal feeding support systems using robotics [4],[5]. Most of the existing systems use joysticks for user interface and brain-machine interface [6]. There is commercially available meal feeding support system so called "My Spoon"[1] by Secom Co., Ltd.[7]. It uses joystick and or button for operation of robot arm. Y.Kohya et al., proposed ultrasonic motor featured robot for

[1] http://www.secom.co.jp/personal/medical/myspoon.html

meal feeding support system [8] while a meal feeding robot system with collaborative motions between robot arm and meal tray is also proposed [9].

Assuming disable persons in this research cannot use their hands and arms so that joystick interface does not work. Brain-machine interface, meanwhile, insists users a psychological impact (Sensor heads have to be attached on their head and/or face). On the other hand, there is no such impact for the proposed computer input system by human eyes only. Robot arm utilized having meal support system with computer input system human eyes only has to be robust against illumination condition changes and a various types of users eye shapes as well as seeing capabilities. Experiments with a variety of conditions have to be conducted.

In the next section, the proposed system is described followed by some experimental results with a variety of conditions. Concluding remarks and some discussions together with future works are described in the final section.

## 2. PROPOSED SYSTEM

The proposed system is composed with visible camera and HMD: Head Mount Display mounted glass and camera mounted robot arm. While user wears the glass, user can look at the outer world which is acquired with the camera mounted at the tip of the robot arm and also user's eye and the surrounding images are acquired with the camera mounted on the glass. System configuration is shown in Fig.1. The only thing user has to do is to look at the desired foods on the tray of the meal displayed onto the screen in the HMD of computer screen. The specification of HMD, camera and robot arm are shown in Table 1, 2 and 3, respectively. Also outlook of the HMD and camera mounted glass and the camera mounted robot arm are shown in Fig.2 and 3, respectively.

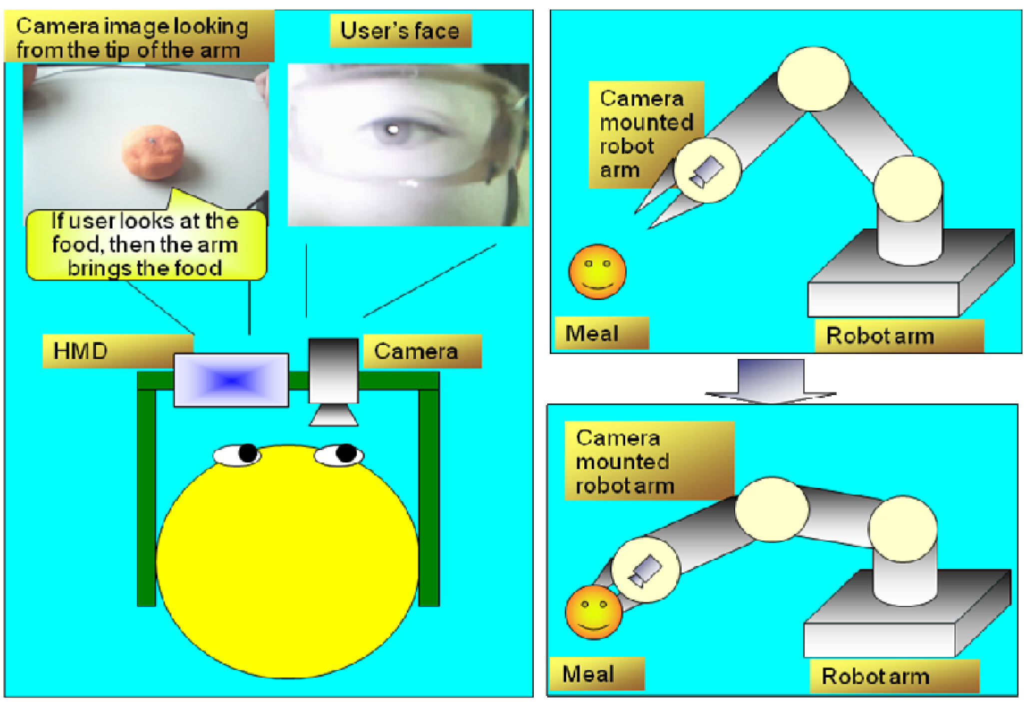



**FIGURE 1:** System Configuration of the Proposed System

**FIGURE 2:** Outlook of the HMD and Camera Mounted Glass

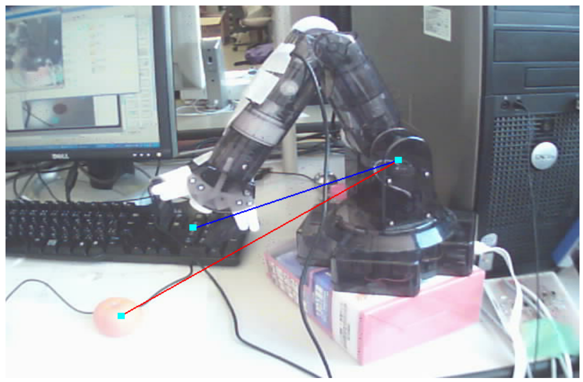


**FIGURE 3:** Outlook of the camera Mounted Robot Arm

| | |
|---|---|
| Pixel size | SVGA(800 × 600) |
| Assumed display distance | 2m |
| Assumed display size | 60 inch |
| Field of view | 42 deg. |
| Input | RGB |
| Working temperature | 0 to 40 deg.C |
| Size | 28mm(W) × 35.24mm(H) × 56mm(D) |
| Weight | 20g |

**TABLE 1:** The Specification of HMD

| | |
|---|---|
| Sensor element | 0.3 million of elements of CMOS |
| Maximum pixel size | 1280 × 960 |
| Maximum viewing angle | 78 deg. |
| Frame rate | 320 × 240 for 30fps |
| Frame rate | 640 × 480 for 15fps |

**TABLE 2:** The Specification of Camera

| | |
|---|---|
| Power supply | Dry battery× 4 |
| Supply voltage | ±3 |
| Maximum load weight | 130g |
| Maximum rotation radius | 360mm |
| Maximum height | 510mm |
| Base plate | W180 × D180mm |
| Total weight | 1050g |
| Controller weight | 150g |
| The number of joints | 5 |
| Base rotation angle | 350 ° |
| Shoulder rotation angle | 120 ° |
| Elbow rotation angle | 135 ° |
| Wrist rotation angle | 340 ° |
| Robot finger | 50mm |

**TABLE 3:** The Specification of Robot Arm

In accordance with the estimated gaze location on the HMD through an analysis of acquired user's face images, the desired foods on the tray can be selected and determined. Tray image is acquired with the camera mounted on the tip of the robot arm. The acquired image can be used to get close to the desired foods with robot arm controls. If the user looks at the desired foods, line of sight of user's eye is pointing to the foods displayed onto HMD screen and both eyes moves simultaneously so that the desired foods can be selected and determined if user's gaze is estimated. In order to extract eye and its surrounding from the acquired face image, adaptive threshold method [10] is used.

As is shown in Fig.4, gaze location on HMD display can be estimated through the line of sight estimation with an analysis of the acquired user's face images. The line of sight is defined as the line between eyeball center and pupil center. Eyeball is assumed sphere with the diameter of 24mm (Typical eyeball size). The cornea can be detected by using the reflectance difference between cornea and sclera. Then pupil center is extracted in the cornea then it can be estimated as is shown in Fig.5. Red point in the image shows pupil center. Thus the line (line of sight) between pupil center and the eyeball center can be estimated [8]. Therefore, if user looks at the desired foods on the tray, the robot arm gets close to the desired foods automatically.


**FIGURE 4:** Process flow for gaze location estimation from the acquired face images

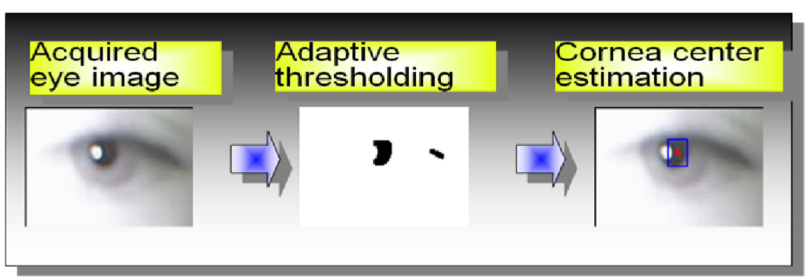



**FIGURE 5:** Process flow for estimation of cornea center

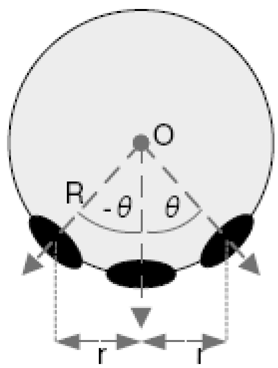
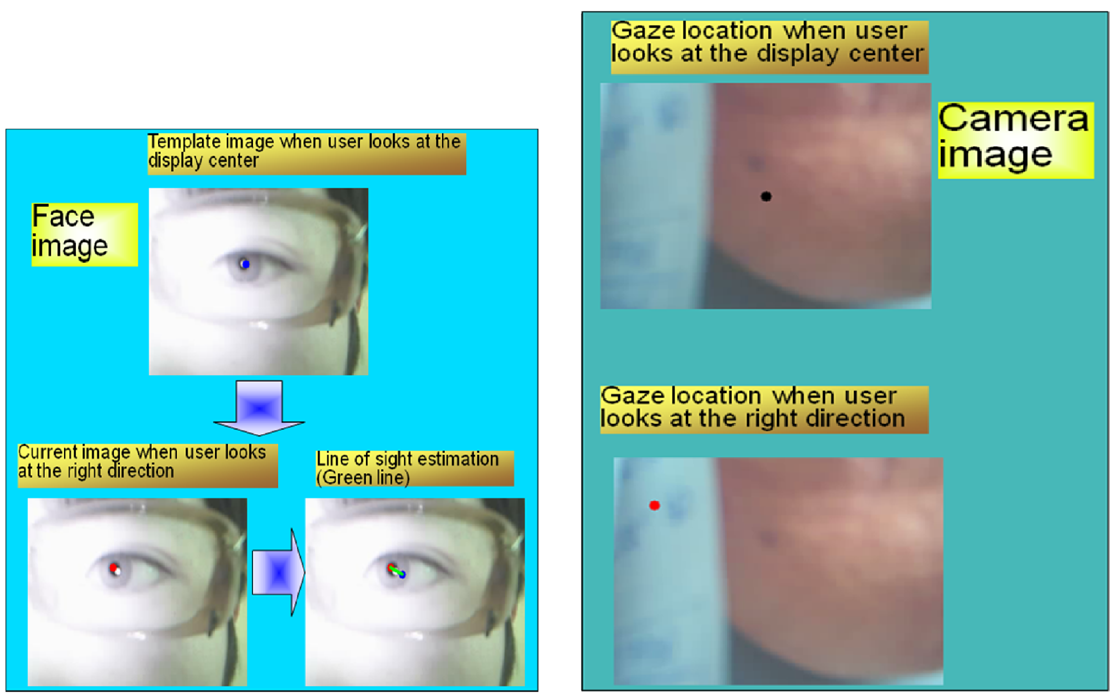



**FIGURE 6:** Definition of eyeball

Eyeball is assumed as is shown in Fig.6. Pupil center is estimated based on the aforementioned manner so that the eyeball rotation angle and the line of sight is estimated as is shown in Fig.7 (a). R is assumed to be 12mm and r is estimated through pupil center movement estimations. Thus gaze location on the HMD display is estimated as is shown in Fig.7 (b).

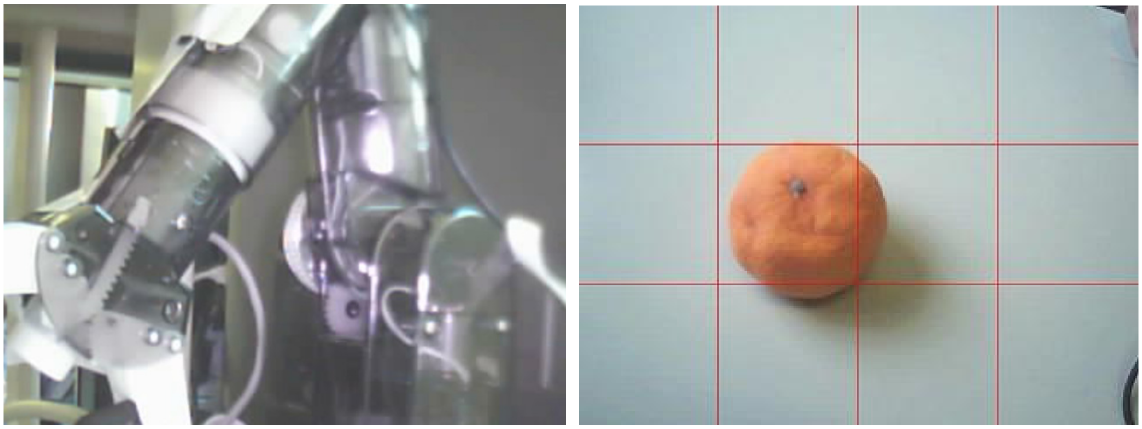
$$r = R\sin\theta \qquad (1)$$
$$\theta = \arcsin(r/R) \qquad (2)$$




(a) Line of sight estimation (b) Gaze location on HMD display estimation

**FIGURE 7:** Process flow for line of sight estimation and gaze location estimation

Fig.8 (a) shows the outlook of the robot arm and Fig.8 (b) also shows one of examples of camera image which is acquired with the camera that is mounted on the top of the robot arm. Objective target of the desired food on the tray can be selected and determined with the camera acquired image. When user is looking at the desired food, the robot arm gets close to the food automatically as is shown in Fig.9. During the food retrieval process, the desired food has to be detected and tracked because the objective target of the desired food is moving in the acquired image. Object tracking is done with optical flow [12] while the robot arm is controlled by its base location movement as well as up and down movements of its elbow and shoulder. These robot arm movements can be controlled automatically in accordance with user's gaze location (ideally the center of the desired food) estimated with the camera acquired image. Fig.10 shows the definitions of the coordinate system and base, shoulder and elbow angles.



(a) Outlook of the robot arm (b) Food on the tray

**FIGURE 8:** Outlook of the robot arm and an example image of food.

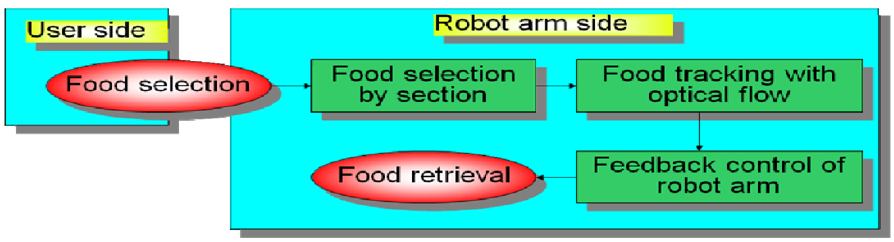
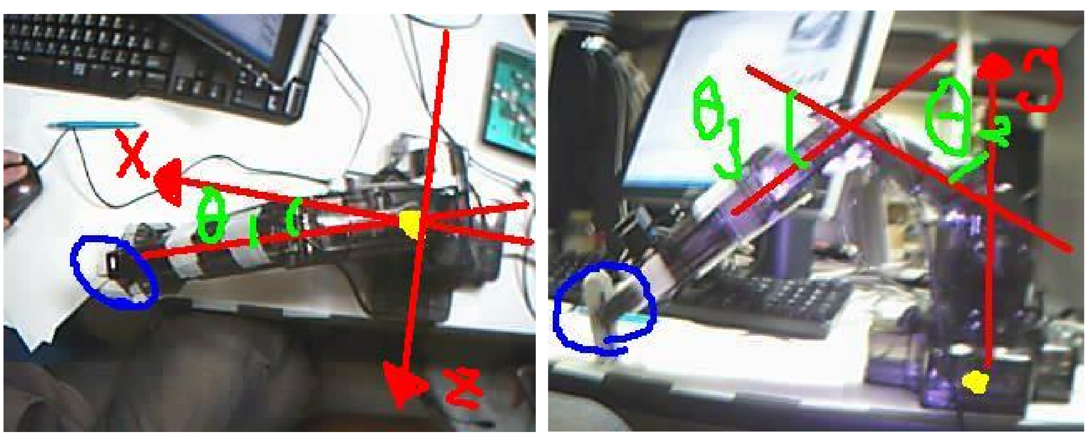



**FIGURE 9:** Process flow for the desired food retrievals with robot arm which is controlled by human eyes only.



$\theta_1$: Base angle, $\theta_2$: Shoulder angle, $\theta_3$: Elbow angle

**FIGURE 10:** Definition of base, shoulder and elbow angles and coordinate system

Blue circle portion in Fig.10 denotes the camera mounted at the tip of the robot arm while yellow dot shows the location of the origin of the robot arm coordinate system.

## 3. EXPERIMENTS

The proposed system can be operated manually and automatically (based on human eyes only).

In the manual mode, the robot arm can be controlled by computer key in of selection processes of base, shoulder and elbow angles control as well as right, left, up and down movements using camera acquired image. On the other hand, the robot arm can be controlled by human eyes only in the automatic mode (the proposed method). Table 4 shows the experimental results for the automatic mode (the proposed method) while Table 5 shows those for the manual mode. There are two types of persons for the test, the persons who have typical eye shape and size eyes and the persons who have narrow eye shape and relatively small size of eyes. Illumination condition was changed during the day time and the night time. Illumination was measured in unit of Lux with radiance measuring instrument from the just above of the surface of the desired food. The time required for retrievals of the desired food is also measured.

There was only one failure that was happened for the person with narrow eye with a week seeing capability of eyes in the night time for relatively high illumination condition. Due to the fact that optical flow was failed so that B(1) gave up to retrieve the desired food. He tried 12 times then he gave up. Only the possible reason for failure is caused by the shape of the eye. It is rather difficult to detecting and tracking the narrow and small eye than the typical normal size of eyes. A(1), A(2), B(2) and C(1) made a success to retrieve the desired food in the automatic mode. Success rate and the required time for retrievals do not depend on illumination condition. Success rate and the required time for retrievals are not influenced by the illumination condition, if the illumination ranges from 165 to 641 Lux. The number of trials for the manual mode is greater than that in the automatic mode with human eyes only so that the required time for retrievals takes much longer. It is rather difficult to retrieve the desired food in the manual mode. Six degree of freedom is not easy to control in the manual mode. Meanwhile it is rather easy to retrieve the desired food in the automatic mode because only thing user has to do is just looking at the desired food then the feedback system control the location of the tip of the robot arm appropriately without consideration of six degree of freedom.

| Person | Eye feature (Seeing capability) | Illumination condition[Lux」 | Success or Fail | The number of trials | Required time for retrievals[ms] |
|---|---|---|---|---|---|
| A(1) | typical(1.5) | Night time(169) | Success | 6 | 42085 |
| A(2) | typical(1.5) | Day time(343) | Success | 4 | 57579 |
| B(1) | narrow(0.05) | Night time(336) | Fail | 2 | |
| B(2) | narrow(0.05) | Night time(338) | Success | 12 | 29908 |
| C(1) | typical(1.5) | Night time(186) | Success | 2 | 21921 |
| Average | | | | 3.2 | 37873.25 |

**TABLE 4:** Experimental results for the automatic mode (the proposed method).

| Person | Eye feature (Seeing capability) | Illumination condition[Lux] | Success or Fail | The number of trials | Required time for retrievals[ms] |
|---|---|---|---|---|---|
| A(1) | typical(1.5) | Day time(241) | Success | 12 | 39623 |
| A(2) | typical(1.5) | Night time(165) | Success | 7 | 32913 |
| B(1) | narrow(0.05) | Day time(207) | Success | 9 | 57048 |
| C(1) | typical(1.5) | Day time(641) | Success | 12 | 59535 |
| C(2) | typical(1.5) | Day time(211) | Success | 9 | 39989 |
| Average | | | | 9.8 | 45821.6 |

**TABLE 5:** Experimental results for the manual mode.

## 4. CONSLUSION & FUTURE WORK

The proposed having meal support system with automatically controlled robot arm by human eyes only is approximately 21% much faster than that with manually controlled robot arm. The number of trials of the proposed system is about one third in comparison to the manually controlled robot arm. The proposed system does work in a variety of illumination condition in the day time and the night time and also work for several types of normal person with different eye shapes and seeing capabilities. It is obvious that the proposed system has to be tested with handicap persons in the near future.

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# USEFul: A Framework to Mainstream Web Site Usability Through Automated Evaluation

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## Abstract

A paradox has been observed whereby web site usability is proven to be an essential element in a web site, yet at the same time there exist an abundance of web pages with poor usability. This discrepancy is the result of limitations that are currently preventing web developers in the commercial sector from producing usable web sites. In this paper we propose a framework whose objective is to alleviate this problem by automating certain aspects of the usability evaluation process. Mainstreaming comes as a result of automation, therefore enabling a non-expert in the field of usability to conduct the evaluation. This results in reducing the costs associated with such evaluation. Additionally, the framework allows the flexibility of adding, modifying or deleting guidelines without altering the code that references them since the guidelines and the code are two separate components. A comparison of the evaluation results carried out using the framework against published evaluations of web sites carried out by web site usability professionals reveals that the framework is able to automatically identify the majority of usability violations. Due to the consistency with which it evaluates, it identified additional guideline-related violations that were not identified by the human evaluators.

**Keywords:** Usability, Automated Usability Evaluation, Usability Guidelines, Usability Problems.

## 1. INTRODUCTION

The International Standards Organization's ISO9241 standard, defines usability as the "effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments" [1].

Whilst there exists a general agreement about the importance of web site usability, especially within the technical communication professional and the academic communities [2, 3, 4], it is given less priority in the commercial sector [3]. In fact, even in its early years, it was noted that on average, the web sites on the World Wide Web were of a poor quality [5, 6, 7, 8].

Problems related to poor usability and accessibility in software and web sites, also prompted some countries to also have their own guidelines and legislation for usability and accessibility of web sites [9, 10]. Additionally, there is less accord about what constitutes usability [2] particularly because some argue that usability is perceived in different ways by different users based on their characteristics such as age, gender, education level, technology skills and culture [11, 12].

Thus, it can be observed that a paradox exists whereby web site usability is proven to be an essential element in a web site, the absence of which confuses users and results in loss of revenue [13, 14] and at the same time it is not commonly applied with the commercial sector. The main question that this study aims to address is “How can web site usability be automated and as a result mainstreamed?"- meaning how can an automated tool be developed that can make it easier and more possible for more web designers and developers to produce usable web sites.

## 2. BACKGROUND

### 2.1 Current limitations that Prevent Web Site Usability from Going Mainstream

Usability Evaluation (UE) is the process of measuring usability and recognizing explicit usability problems [15]. Its main goal is to identify the main issues in the user interface that may lead to human error, terminate the user interaction with the system and cause user frustration [16].

Although there exist a number of widely accepted usability evaluation techniques such as Heuristic Evaluation [17], Cognitive Walkthrough [18], Think aloud testing and Query techniques [15, 19], the development of usable web sites is not common because of the following limitations:

- Usability evaluation requires the engagement of experts to conduct it, and there is a shortage of such experts [20, 21, 13, 22].
- The process of conducting usability evaluation is expensive and some companies do not have the finance to afford it [23, 24].
- Conducting usability evaluation and improvement of web sites is becoming increasingly difficult because of the number of web sites being developed, their size and the regularity at which they are updated [25].
- Time is an issue since the web site life cycle is fast due to market pressure and absence of distribution barriers [5]. So as to meet such demanding deadlines, evaluation many be overlooked, thus resulting in less usable web sites.
- Tobar et al. [24] state that all forms of quality measurement of a web site such as usability evaluation can only be carried out up to a limited depth.
- Studies also show inconsistencies in the reported usability violations when the same web sites were evaluated by different usability experts [26, 20, 27, 28].

### 2.2 How Automation Helps in Mainstreaming Web Site Usability

In this study, automation is being chosen as the primary method to mainstream web site usability. This is because our proposed framework is based on research carried out by Beirekdar et al. [20], Ivory and Hearst [29] and Brajnik [5] who identify automated usability evaluation as a viable approach that can overcome the limitations of its manual counterpart. Since most of the advantages of automating web site usability that they propose actually overcome the current limitations, outlined in Section 2.1 of this document, then automation has been chosen as the technique to mainstream web site usability. This is because they state that automated web site evaluation:

- **Reduces the costs of usability evaluation:** Through automation, the evaluation can be done more quickly and hence more cheaply.
- **Reduces or eliminates the need for usability experts to carry out the usability evaluation:** The use of such a tool will be of assistance to designers and developers who do not have such expert skills in web site usability.
- **Overcomes inconsistency in the usability problems that are identified:** By removing the human element, automation removes the inconsistencies in the usability problems that are detected as well as any misinterpretations and wrong application of usability guidelines.
- **Enables the prediction of the time and costs of errors across a whole design:** Since automated evaluation tools perform usability evaluation methodically, they are more consistent and cover a wider area in their evaluation and thus, one can better predict the time and cost required to repair usability errors that are identified

- **Increases the coverage of the usability aspects that are evaluated:** Automation overcomes commercial constraints such as those associated with time, cost and resources, which typically limit the depth of evaluation
- **Enables the evaluation between different potential designs:** Commercial constraints limit the evaluation against one design or a group of features. Automated evaluation software provides designers with an environment where alternative designs can be evaluated.
- **Facilitates the evaluation in various stages of the design process:** An interface can be evaluated and any usability issues identified and resolved early, thus saving time and costs that would be incurred should it be addressed at a later stage.
- **Is of immediate value in the web design and development domain:** Brinck and Hofer [25] state that due to the large number of web designers and developers, a tool that enables the evaluation of a web site is something that will appeal to this large community.

### 2.3 Attempts at automating web site usability evaluation

Chi et al [6] state that there are two types of tools that can perform automated usability evaluation. These categories refer to tools that:

- Make use of **conformance to standards**
- Try to **predict** the usage of a web site

Through the research carried out for this study, four tools have been identified that perform the usability of a web site, all of which fall in the second category. These are Cognitive Walkthrough of the Web - CWW [30] Web Tango [31], WebCriteria Site Profile [5] and Bloodhound [6]. All three solutions base their usability evaluation through usage prediction - something which various researchers such as Groves [32], Winckler et al. [33] and Murray and Costanzo [34] argue against since this method is based on prediction algorithms that can provide misleading data.

## 3. MAINSTREAMING WEB SITE USABILITY THROUGH USEFUL

### 3.1 The Components of the USEFul Framework

The framework that is being proposed in this study has been named USEFul (USability Evaluation Framework). Unlike the previous attempts at automated usability evaluation, USEFul falls in the first category proposed by Chi et al [6].

This is because it is based on research conducted by Jeffries et al. [21], Otaiza et al. [19] and Tobar et al. [24], who identify Heuristic Evaluation, that is, the evaluation of the interface with respect to a set of usability principles [35] as the usability evaluation technique that manages to detect the majority of global usability issues, from all the usability evaluation techniques that they evaluated. Similarly, studies by Comber [7], Ivory and Hearst [29] and Tobar et al. [24], show that adherence to guidelines can effectively contribute towards making a web site more usable.
Thus, the USEFul framework will reference web site usability guidelines and use them to automatically assess the usability of a web site that is being evaluated.

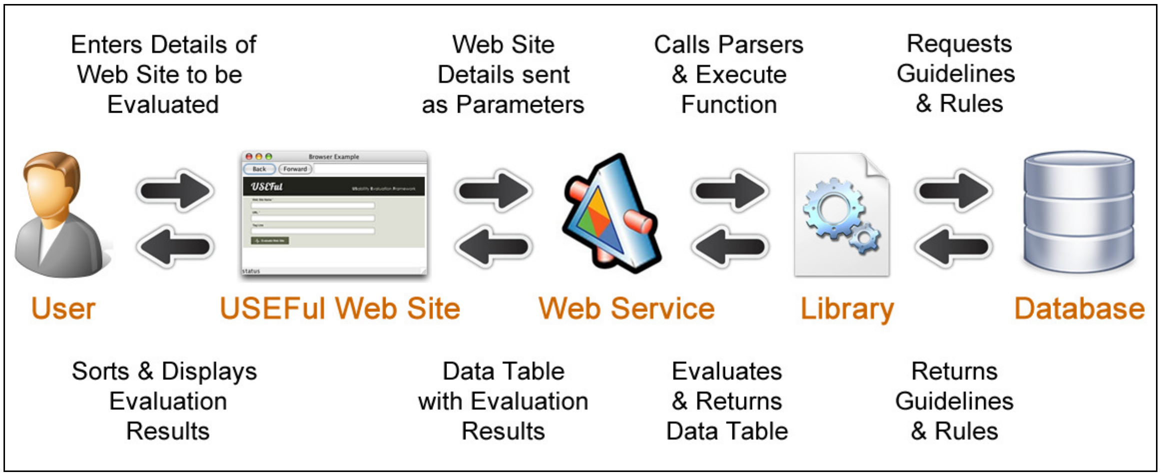


**FIGURE 1:** A visual representation of the USEFul framework (Source: Authors)

The different components of the USEFul framework as illustrated in Figure 1 are the:

- **User** - the person who is conducting the usability evaluation of a web site
- **Web site** - the means by which the user can interact with the USEFul framework. To specify which web site needs to be evaluated, the user needs to key in the web site's name, its tag line and URL.
- **Web service** - The web service communicates with the library by calling the execute function from the library and passes it the parameters that it needs to evaluate the web site. Once the evaluation is complete, the web service passes the results of the evaluation back to the web site.
- **Library** - The library contains the program that carries out the evaluation. In order to carry out the evaluation, it retrieves the data from the database.
- **Database** - The database is an SQL relational database that contains 4 tables

  - **Usability Category table** - stores the usability categories available (Section 3.1)
  - **Implementation Level table** - stores the implementation levels available (Section 3.2)
  - **Guidelines Definitions table** - stores the guidelines that will be used in the framework, expressed in natural language. This table also stores the Priority Rating (Section 3.2) of each guideline and references the usability and implementation level tables.
  - **Rule Type 1 table** - In this table, the guidelines from the guidelines definitions table that have green or amber implementation level (Section 3.2) are expressed in a form that the library can interpret to carry out the evaluation. For each record, the fields contain the HTML tag along with its additional data such as its attribute and size that the library needs to search for so as to find the pattern that identifies a specific guideline. The rule type 1 table also allows the comparison or searching of two HTML tags or tags within tags. An important column in this table is the "ruleSuccess" column as the fields in it store a value that the library interprets as the conditions under which the guideline is considered to have been violated or not. This is important since it distinguishes between guidelines that must be adhered to and thus must be present in the web site and those that must never be found or can only be found once as otherwise they would cause a usability violation.

At this point, it is worth mentioning that the current build of the USEFul framework contains just 1 rule type (Rule type 1 table), that enables the library to identify the guidelines that relate to HTML tags or CSS selectors. It is envisaged that future builds will enable the addition of new rule types such as ones that enable the library to evaluate usability guidelines related to images and other resources used by the web site. Also, should new structuring tools such as a JavaScript parser be incorporated into the framework, then these would require new rule types to be incorporated.

### 3.2 The Set of Guidelines That Will be Used by the USEFul Framework

Over the years, a number of usability guidelines have been published such as those by Smith and Mosier [36], Norman [37], Nielsen [38], Comber [7], Sano [39], Borges et al. [27], Spool et al. [40], Fleming [41], Rosenfeld and Morville [42], Shneiderman [43], Nielsen [44], Dix et. al. [15] and Nielsen and Loranger [45].

However, the problem with Usability guidelines is that there is no set of guidelines that has been established as a standard [15]. Thus, a set of 240 guidelines has been compiled for this study from the results of usability studies carried out by researchers and experts in the fields of cognitive psychology, technical communication, computer science, human factors and usability.

Since most of the proposed guidelines have been retrieved from the U.S Department of Health and Human Services' (HHS) Research-Based Web Design & Usability Guidelines [46], the same categorization has been used, that is, each guideline was placed in 1 of the 15 categories shown in Table 1

| Usability Category | Number of Guidelines |
|---|---|
| Optimizing the user experience | 29 |
| Hardware and software | 4 |
| The homepage | 12 |
| Page layout | 9 |
| Navigation | 27 |
| Scrolling and paging | 3 |
| Headlines, titles and labels | 18 |
| Links | 21 |
| Text appearance | 18 |
| Lists | 13 |
| Screen based controls (widgets) | 27 |
| Graphics, images and multimedia | 17 |
| Writing web content | 18 |
| Content organization | 8 |
| Search | 16 |
| **Total Guidelines** | **240** |

**TABLE 1:** The number of guidelines used by the USEFul framework in each category (Source: Authors)

### 3.3 Assigning the Priority Rating and Level of Implementation to each Guideline

Each guideline used in the USEFul framework has been assigned an **Implementation Level** which denotes the ability (or otherwise) to translate that guideline into a form which can then be referenced by the program. This gives an indication as to what automation level each guideline has. The parameters that will be used for this classification are as shown in Table 2:

| Implementation Level Category | Interpretation |
|---|---|
| Green | • Guideline can be fully implemented in the database within the USEFul framework.<br>• The framework is able to automatically determine whether this guideline applies to the web site being evaluated.<br>• The results returned by the framework when referring to this guideline are conclusive since these types of guidelines are typically measurable, with clearly defined parameters. |
| Amber | • Guideline is harder to fully implement in the USEFul framework.<br>• Certain patterns that automatically identify if this guideline may apply to the web site being evaluated have been implemented in the database.<br>• This guideline can be converted into a "green" guideline by incorporating within the USEFul framework additional Artificial Intelligence algorithms.<br>• The results outputted by the framework when referring to this guideline consist of data that can assist the human evaluator in checking whether it applies to the web site being evaluated |
| Red | • This guideline is typically abstract and requires user intervention or very advanced algorithms from the field of Artificial Intelligence or additional technology to make it possible for it to be implemented in the framework.<br>• Through the use of advanced algorithms or technology, it can be converted into "amber" or "green" guideline<br>• In its current build, the framework lists this guideline so that the human evaluator can manually check if it applies to the web site being evaluated |

**TABLE 2:** How the guidelines should be interpreted in terms of their Implementation Level (Source: Authors)

Since the resources to tackle usability violations are typically scarce, the evaluator carrying out manual usability evaluation prioritizes them so that the violations that cause the highest problems are addressed first [47, 45].

One of the most used prioritization techniques is the severity scale, whereby each guideline is given a severity rating [48]. For this project a severity scale called **Priority Rating** (PR) is proposed, whereby each guideline is assigned a PR from 1 to 5 where a guideline with PR 5 is very important in terms of its contribution towards making a web site usable, whilst a guideline with PR 1 provides minor contribution. This prioritizes the list of usability violations identified by the program.

### 3.4 Incorporating the Guidelines into the SQL Database

Usability guidelines are occasionally abstract and difficult to interpret and apply [26, 20, 27, 28, 49]. This has been addressed in the USEFul framework through the use of the guidelines definitions and rule type 1 tables (Section 3.1). The process through which a guideline is entered into these 2 tables is illustrated below through the use of one of guideline#81 which is one of the guidelines used in the USEFul framework:

#### 3.4.1 Guideline Expressed in Natural language

Guideline#81: URLs should not be complex and should ideally be less than 50 characters. This is beneficial for both usability and SEO [45]

#### 3.4.2 Guideline as Entered in the Guidelines Definitions Table

When the guideline is entered in the guidelines definition table, its primary key is 81. The guideline and its explanation have been split into the fields under the "Guideline" and "Reason" columns respectively. The value in the field "ruleType" is 1 since this guideline needs to be evaluated using the rule type 1 rule. The guideline is a green guideline, hence the value 1 under the "ruleCat" column and its Priority Rating is 5, hence the reason why there is a "5" under the ruleSeverity column. Since this guideline belongs to the "navigation" usability category, the value "5" has been entered in the field under the ruleGroup column.

| pk | Guideline | Reason | ruleType | ruleCat | rule Severity | rule Group |
|---|---|---|---|---|---|---|
| 81 | URLs should not be complex | URLs should ideally be less than 50 characters. Such URLs are beneficial for both usability and SEO | 1 | 1 | 5 | 5 |

**TABLE 3:** How guideline#81 is represented in the guidelines definition table (Source: Authors)

### 3.4.1 Guideline as Entered in the Rules Type 1 Table

To check whether the guideline is found in the parsed HTML, the execute function needs to search for the following pattern:

```
<a href="any text as long as it is less than 70 characters"> .. </a>
```

Therefore, the guideline is converted to a form that the execute function can understand and this is stored as a record in the rule type 1 table (Section 3.1) as shown below:

| pk | ruleFk | tagA | attributeA | valueA | sizeA | tagB | attributeB | valueB | sizeB | rule Command | compare Operator | rule Success | must Succeed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 81 | a | href | *NULL* | 70 | *NULL* | *NULL* | *NULL* | *NULL* | *NULL* | < | True | 0 |

**TABLE 4:** How guideline#81 is represented in the rules type 1 table (Source: Authors)

Thus, the value "81" is a foreign key that references the primary key "81" in the Guidelines Definition table. The execute function will look for is the "a" tags which have an "href" attribute as stated by the contents in the fields under the "tagA" and "attributeA" columns respectively. The exact content in between the inverted commas of the "href" attribute is irrelevant, hence the reason for the *NULL* value in the field under the "valueA" column.

However, for the guideline not to be violated, this content needs to be less than 70 characters long, as stated by the contents in the fields under the "compareOperator and "sizeA" columns respectively. Since the guideline is not dependent on any other HTML tags, the fields under the four tag B columns are all set to *NULL*. If the guideline matching the pattern in this record is found, then it is a good thing, hence the reason why the value under the "ruleSuccess" column is True. Also, for the guideline to succeed, all the content of all "href" attributes within all the "a" tags found must be less than 70 characters. This is set by the "0" value in the field under the "mustSucceed" column.

## 4. HOW THE PROPOSED FRAMEWORK EVALUATES WEBSITE USABILITY

This section will describe the process that takes place from when the user accesses the USEFul web site and keys in the parameters pertaining to the web site they would like to evaluate to when the results of the usability evaluation are reported on the web site. This description will thus discuss on a high level the interactions that take place between the various components within the framework represented in Figure 1.

### 4.1 Step 1 - The user passes the data to the web site

This step refers to when the user states what web site the USEFul framework will need to evaluate. They do this by filling in the text fields pertaining to the web site's name, URL and (optionally) the tag line. The website's GUI can be seen in the screenshot below (Figure 2)

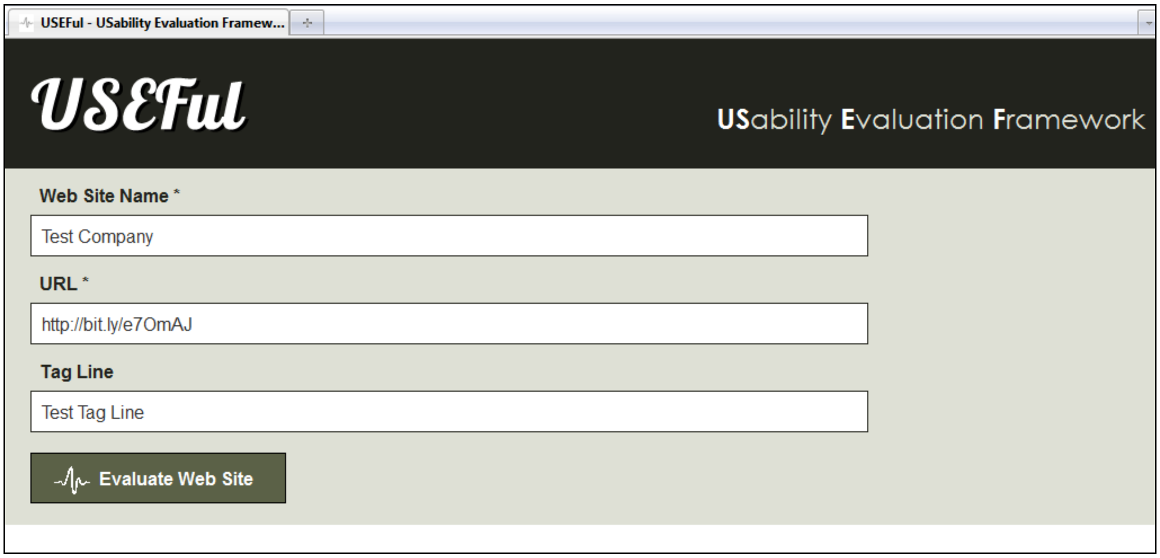


**FIGURE 2:** Screenshot of the USEFul web site (Source: Authors)

### 4.2 Step 2 - The Web Site Passes the Data to the Web Service

When the user fills in the data in Step 1 and presses the "Evaluate Web Site" button, the web site passes the data as parameters to the web service.

### 4.3 Step 3 - The Web Service Configures the Library

When the web service receives the parameters from the web site, it communicates with the library and creates a new instance by setting the configuration values in the library according to these parameters. It is important to note that in reality, the library is actually contained within the web service. The only reason why the library was illustrated as a component outside the web service in Figure 1 is to create a distinction between the two components for explanation purposes. Therefore, the phrase "communicates" is being used to illustrate the flow of data between the library and the web service.

Thus, the web service sets the path of the web site, the company name and the tag line. The web service then uses the library's functionalities to load and parse the web site to create parsed HTML and CSS documents. These parsed documents are stored in the web service in static variables.

### 4.4 Step 4 - The Web Service Fetches the Guidelines

The web service communicates with the library which in turn communicates with the SQL database to fetch the data stored in the guidelines and rule type tables. The returned data is stored inside the web service in a **data table** as shown in Table 5 below:

| | Guideline Definition | Rule Type Properties | Results Fields |
|---|---|---|---|
| 1 data row ⇨ | | | |

**TABLE 5:** The Structure of the Data Table stored in the Web Service (Source: Authors)

The components of the data table shown in Table 5 are the following:

- **Guideline definition:** This contains a copy of the data found in the guidelines definitions table (Section 3.1)
- **Rule type properties:** This field contains a copy of the rules type 1 table (Section 3.1)
- **Results fields:** The results fields are additional fields initially set as empty when the data table is created in the web service. These fields will eventually contain the results that the web service will communicate back to the web site after the evaluation is completed. These are:
  - Tags: will contain the number of times the HTML tag or CSS selector found in the field under the rule type properties column in the data row is found.
  - Success: The number of tags or selectors found whose properties match the properties of the guideline being referenced
  - Fail: The number of tags or selectors whose attributes match the properties of the guideline being referenced but their value or size properties do not match
  - Null: The number of tags or selectors whose attributes, sizes or properties do not match with the property of the guideline
  - Success%: This value is the result of the equation Success/(Tags-Null) x 100
  - Passed: This field will eventually contain a True/False value that will indicate whether the guideline has been violated or not

**4.5 Step 5 - The Web Service Uses the Library to Evaluate the Web Site**

At the end of Step 4, the web service contains a copy of the parsed HTML and CSS documents which are stored in static variables. It also has a data table as shown in Table 5.

The web service then takes the first data row and calls the execute function from the library. The execute function takes 1 data row (1 row of the data table as indicated in Table 5) as a parameter. When the execute function in the library receives the data row from the web service, it sees what rule it has to work on in order to evaluate whether the usability guideline defined in that data row is being violated.

We will use guideline#81 as an example to illustrate the steps the library performs to assess whether the web site being evaluated adheres to a guideline or if it violates it. It is being assumed that guideline#81 has been entered in both the guidelines definition table and the rules table as indicated in Tables 3 and 4 respectively.

When the web service passes calls the execute function with the data row pertaining to guideline#81, each time the execute function is run, and it finds an "a" tag it follows the logic tree shown in Figure 3 below. As it can be seen in Figure 3, the execute function can take different paths, depending on what the fields contain and the type of pattern matching that it needs to perform.

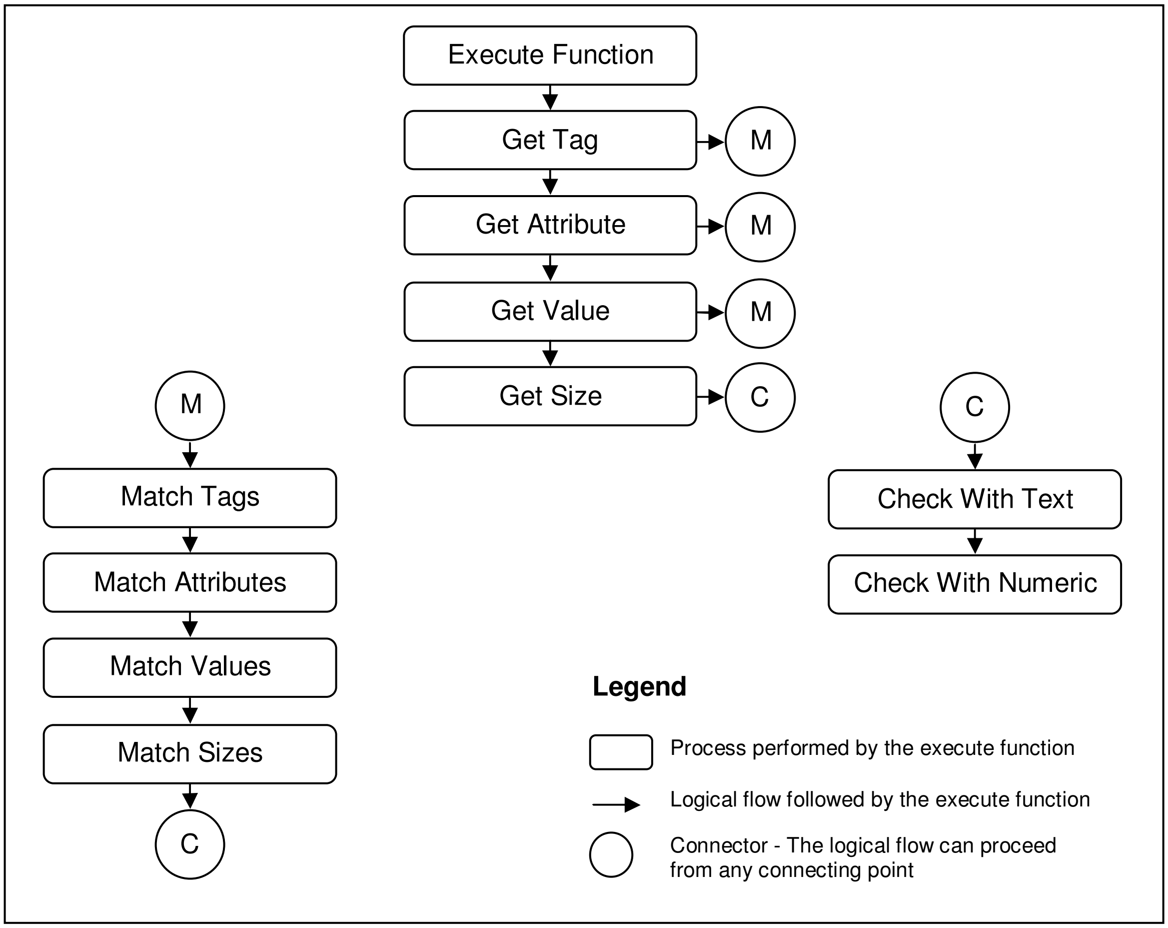


**FIGURE 3:** The Logic Tree for Rule Type 1 (Source: Authors)

At the end of this process, the execute function returns the evaluation result which can have 1 of 3 values: True, False or Null. In the case of guideline#81, these are interpreted as follows:

- True: The "a" tag has an "href" attribute whose content is less than 70 characters
- False: The "a" tag has an "href" attribute whose content is 70 characters or more
- Null: The "a" tag does not have an "href" attribute

Suppose that the execute function finds 3 instances of the "a" tag in the parsed HTML document and these are as follows:

- True: 2
- False: 1
- Null: 0

For each evaluation result, the execute rule compares it with the value of the field under the "ruleSuccess" column in Table 4. During the same process, it uses the result of the comparison to increment the counters of the values that will be written in the results fields of the data table in the web service. The method of comparison is modeled on the XNOR truth table and can be seen in Table 6 below:

| Input A (Evaluation Result) | Input B (ruleSuccess) | Output (A XNOR B) |
|---|---|---|
| False: Guideline not found | False: Bad guideline | True: Increment success counter |
| False: Guideline not found | True: Good guideline | False: Increment fail counter |
| True: Guideline found | False: Bas guideline | False: Increment fail counter |
| True: Guideline found | True: Good guideline | True: Increment success counter |
| Null: Guideline not applicable | True: Good guideline | Null: Increment null counter |
| Null: Guideline not applicable | False: Bad guideline | Null: Increment null counter |

**TABLE 6:** How guideline#81 is represented in the guidelines definition table (Source: Authors)

Thus, assuming that in the case of the guideline#81 example, the sequence in which the evaluation results are issued by the execute function are 2 True, 1 False and 1 null, then the execute rule would make the following comparisons:

| Input A (Evaluation Result) | Input B (ruleSuccess) | Output (A XNOR B) |
|---|---|---|
| True | True | True: Increment success counter |
| True | True | True: Increment success counter |
| False | True | False: Increment fail counter |

**TABLE 7:** The comparisons made by the execute function for the guideline#81example (Source: Authors)

In this way, the values for the results fields of the data row for guideline#81 in the web service (Table 5) would be as shown in Table 8 below:

| Results Field | Value |
|---|---|
| Tags | 3 |
| Success | 2 |
| Fail | 1 |
| Null | 0 |
| Success% | 66.7 |
| Passed | *NULL* |

**TABLE 8:** The values in fields of the data row for guideline#81 (Source: Authors)

As can be seen in the table above, at this stage, it has not been determined whether the guideline has passed or not. In fact, to set this value, the execute function looks up the value of the field under "mustSucceed" in Table 4 to see under which conditions it can be stated that guideline#81 has not been violated.

Since the value in this case is "0", the execute rule interprets it that for the guideline not to be violated, this guideline must not fail, meaning that the fail counter in Table 8 should be "0". Since this is not the case, the execute rule sets the value of the "Passed" field in Table 8 to "FALSE". This effectively means that the guideline has been violated.

This value is then stored in the passed field of the data row for guideline#81 in the web service.

### 4.6 Step 6 - The Web Service Sends the Data Table to the Web Ste

Once the data table is complete, the web service sends it to the web site which creates 3 data views, one for each implementation level. It also sorts the violations in each implementation in descending order of priority rating and displays them as shown in Figure 4.

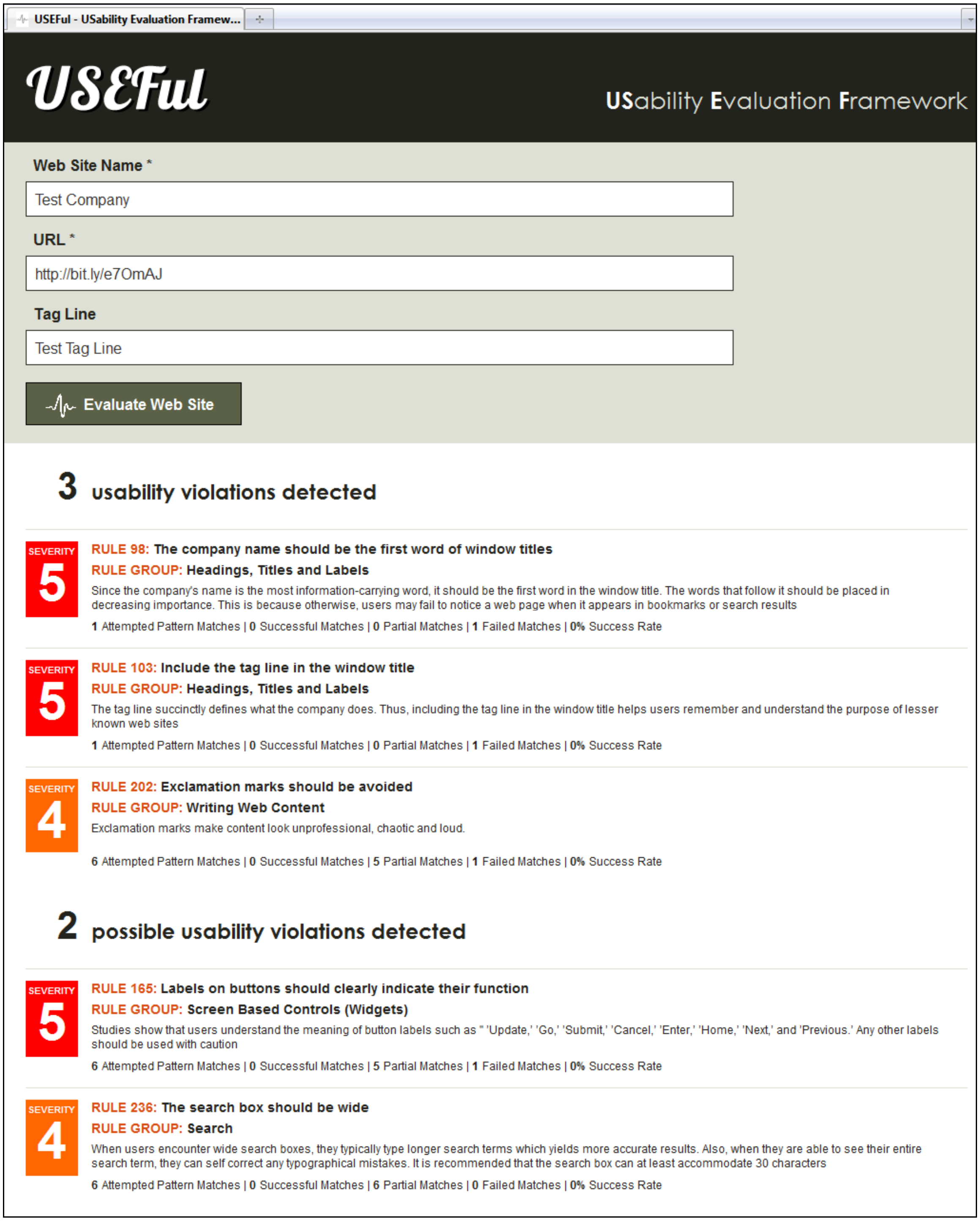


**FIGURE 4:** Screenshot showing evaluation results carried out by the USEFul framework (Source: Authors)

## 5. EXPERIMENTS AND RESULTS

Since web site usability professionals are scarce (a current limitation mentioned in Section 2.1), it was decided that the effectiveness of the USEFul framework will be assessed by comparing the results of the evaluations carried out on web sites against published evaluations of the same web sites carried out by web site usability professionals.

The most reliable source for this evaluation was identified to be the book "Homepage Usability - 50 Websites Deconstructed" by Nielsen and Tahir [50]. The reasoning behind this chosen method of experimentation is based on the following points:

- Dr. Jakob Nielsen is considered to be a web usability guru [51, 52] and has been hailed as "one of the world's foremost experts in web usability" [53].
- The book itself illustrates in a very clear manner the usability violations that have been identified by Nielsen and has received numerous positive reviews [54, 55].
- Nielsen evaluates the web sites featured in this book by referencing web site usability guidelines. This usability evaluation technique is the same technique used by the USEFul framework. This eliminates any possibilities that any difference in the list of identified violations is as a result of different techniques being employed.
- The set of guidelines used by Nielsen for this evaluation is a subset of the HHS Research-Based Web Design & Usability Guidelines [46]. In fact, this book is listed as one of the cited sources. As stated in Section 3.2, the majority of the guidelines implemented in the USEFul framework are from the HHS guidelines.
- Although the HHS Research-Based Web Design & Usability Guidelines have been retrieved in February 2011 and thus it can be assumed that they are still relevant today, any flaws in these guidelines does not affect the performance of the USEFul framework since the guidelines are not hard coded into the library itself. Moreover, using the same set of guidelines as those used by the human evaluator for these tests eliminates the possibility that any discrepancies in the results were due to different sets of guidelines being used.

On inspection of the results reported by evaluation carried by Nielsen and Tahir it was noticed that they also mention some positive usability characteristics. The guidelines that have been observed which have led to these positive traits have also been incorporated in this experiment. Since the USEFul framework only reports usability violations, the absence of these guidelines in the list of detected violations was thus interpreted as a positive result. In this regard, since what Nielsen and Tahir reported were both positive as well as negative comments, the term "**usability aspects**" will be used instead of usability violations so as to avoid the negative connotation associated with the word "violation".

Due to their expertise in web site usability, Nielsen and Tahir also list a number of positive as well as negative usability aspects which are specific to the web site being evaluated and their linkage to any of the guidelines could not be established. These **site-specific** aspects were incorporated in this study with the red guidelines since they could not be automatically evaluated by the USEFul framework in its present form.

Ten web sites from the book were selected on the basis that their evaluation contained less site-specific recommendations and more green and amber guideline related usability aspects. This means that from the authors' evaluation, it was easier to identify which guidelines from the HHS Research-Based Web Design & Usability Guidelines were being violated. Special attention was taken to select web sites that violated different guidelines so as to increase the set of guidelines that will be incorporated into the database for evaluation.

So as to ensure that the versions and contents of the web sites evaluated are identical to the ones evaluated by Nielsen and Tahir, the Internet Archive's Way Back Machine [56] was used. Using this tool, the exact web sites were loaded by utilizing the dates present on the screenshots in the book. Based on these criteria, the 10 web sites chosen for this experiment are those found in Table 9.

| Web Site | Tag Line | URL |
|---|---|---|
| About | The Human Internet | http://replay.waybackmachine.org/20010611062521/http://www.about.com/ |
| Accenture | Now It Gets Interesting | http://replay.waybackmachine.org/20010711142024/http://www.accenture.com/ |
| Asia Cuisine | Asia's Leading Food and Beverage Portal | http://replay.waybackmachine.org/20010703030929/http://www.asiacuisine.com.sg/ |
| Barnes & Noble | (No Tag Line) | http://replay.waybackmachine.org/200102031220/http://bn.com/ |
| BBC Online | Welcome to the UK's Favourite Website | http://replay.waybackmachine.org/20010806173705/http://www.bbc.co.uk/ |
| Boeing | Forever New Frontiers | http://replay.waybackmachine.org/20010522194801/http://www.boeing.com/ |
| DIRECTV | America's Leader in Digital Home Entertainment | http://replay.waybackmachine.org/20010629015718/http://www.directv.com/ |
| FedEx | (No Tag Line) | http://replay.waybackmachine.org/20010525031739/http://www.fedex.com/us/ |
| Red Herring | The Business of Innovation | http://replay.waybackmachine.org/20010515222459/http://redherring.com/ |
| The Art Institute of Chicago | (No Tag Line) | http://web.archive.org/web/20010630180812/www.artic.edu/aic/index.html |

**TABLE 9:** The web sites that were used for this experiment (Source: Authors)

So as to be able to identify the usability violations identified by Nielsen and Tahir in these web sites 62 guidelines (36 Green, 27 Amber and 0 Red / Site-Specific guidelines) from the set of guidelines mentioned in Section 3.2 were used for this experiment. The results of the evaluations can be seen side by side in Table 10:

| Web Site | Usability aspects identified by Nielsen and Tahir | | | | Nielsen and Tahir's usability aspects identified by USEFul | |
|---|---|---|---|---|---|---|
| | Green | Amber | Red | **Total** | **Results 1:** As a percentage of implementable usability guidelines (Green & Amber) | **Results 2:** As a percentage of **total** usability guidelines (Green, Amber, Red & Site Specific) |
| About | 7 | 7 | 11 | **25** | 100.00% | 56.00% |
| Accenture | 6 | 8 | 13 | **27** | 85.71% | 44.44% |
| Asia Cuisine | 7 | 3 | 11 | **21** | 100.00% | 47.62% |
| Barnes & Noble | 11 | 4 | 13 | **28** | 93.33% | 50.00% |
| BBC Online | 17 | 6 | 15 | **38** | 100.00% | 60.53% |
| Boeing | 9 | 3 | 12 | **24** | 100.00% | 50.00% |
| DirectTV | 14 | 1 | 12 | **27** | 86.67% | 48.15% |
| FedEx | 10 | 8 | 11 | **29** | 100.00% | 62.07% |
| Red Herring | 9 | 3 | 17 | **29** | 91.67% | 37.93% |
| The Art Institute of Chicago | 7 | 5 | 10 | **22** | 100.00% | 54.55% |
| **Total** | 97 | 48 | 125 | **270** | **Average: 95.86%** | **Average: 51.48%** |

**TABLE 10:** Usability evaluations carried out by Nielsen & Tahir against USEFul (Source: Authors)

As can be seen in the figures presented in the column Results 1 of Table 10, the USEFul framework was able to correctly identify the guideline-related usability aspects, 95.86% of the time when compared to Nielsen and Tahir's manual evaluation. When the code was inspected to identify why there was a 4.14% discrepancy it was found that the main reason why the framework failed was due to bad coding in the web sites being tested. In fact, the primary cause was the use of images to represent text instead of using actual text. So as to minimize the impact of this limitation, most of the guidelines' interpretation in the table also referenced the alt attribute of images. When the alt attribute was not present, then the USEFul framework was not able to parse the text represented by those images since it does not currently have Optical Character Recognition (OCR) facilities. Additionally, this discrepancy can also be attributed to the lack of proper usage of certain HTML tags such as the use of the <p> tag instead of the <h1>..<h6> tags for headings.

Since only 53.71% of the usability aspects were directly related to green and amber guidelines, it can be seen that overall, the number of violations reported by the USEFul framework on average relates to just 51.48% of the total usability aspects identified by Nielsen and Tahir. This finding shows why various researchers [6, 57, 29, 58] suggest that any tool that automatically evaluates a web site cannot replace a human being. In this case, because of their experience and expertise in web usability, Nielsen and Tahir were able to identify almost as many usability guidelines that have been classified as red guidelines or site-specific recommendations as those that were classified as green or amber. In this regard, it is clear that the USEFul framework cannot implemented without the inclusion of a human evaluator.

An interesting observation in these experiments is that since the USEFul framework checks for the presence of each guideline in the database, it performs a consistent evaluation and thus it was able to identify more usability violations in each of the tested web sites. At this point it is important to note that the term being used is usability violations since the USEFul program can only report usability violations. The HTML and CSS code was then inspected manually so as to confirm that these additional usability violations were correct.

When the additional usability violations identified by the USEFul framework are compared to the total aspects identified by Nielsen and Tahir (manually), it can be noted that the framework was able to identify on average 128.15% usability violations (Table 11: column Results 3) i.e. 28.15% more violations than what Nielsen and Tahir actually identified. The total number of additional violations identified are shown in Table 10.

| **Web site** | **Additional usability violations detected by USEFul** | | | **RESULTS 3:** Total usability aspects detected by USEFul as a percentage of **total** usability aspects identified by Nielsen & Tahir |
|---|---|---|---|---|
| | Green | Amber | **Total** | |
| About | 11 | 9 | **20** | 136.00% |
| Accenture | 13 | 9 | **22** | 125.93% |
| Asia Cuisine | 16 | 15 | **31** | 195.24% |
| Barnes & Noble | 13 | 12 | **25** | 139.29% |
| BBC Online | 7 | 10 | **17** | 105.26% |
| Boeing | 9 | 8 | **17** | 120.83% |
| DirectTV | 9 | 7 | **16** | 107.41% |
| FedEx | 9 | 9 | **18** | 124.14% |
| Red Herring | 14 | 12 | **26** | 127.59% |
| The Art Institute of Chicago | 6 | 9 | **15** | 122.73% |
| **Total** | 107 | 100 | **207** | **Average: 128.15%** |

**TABLE 11:** Additional usability violations identified by the USEFul framework (Source: Authors)

This means that despite the fact that only 53.71% of the usability attributes identified by Nielsen and Tahir can be converted into green and amber guidelines, the USEFul framework was still able to detect 28.15% more usability violations using this limited set of 62 guidelines.

Another interesting find in these experiments suggests that through the USEFul framework, a usability expert is still likely to identify more usability violations. Table 12, which summarizes the results of all the tests carried out with the 10 web sites, illustrates this point.

| Item # | | Usability aspects detected by | |
|---|---|---|---|
| | | Nielsen & Tahir | USEFul |
| 1 | Number of web sites evaluated | 10 | 10 |
| 2 | Green and Amber guideline-related usability aspects detected | 145 | 139 |
| 3 | Red and Site-Specific usability aspects detected | 125 | 0 |
| 4 | Additional usability violations detected | 0 | 207 |
| | **Total** | **270** | **346** |

**TABLE 12:** Summary of the results from the experiments

From the results shown in Table 11, Nielsen and Tahir were able to comment on an average of 27 usability aspects per web site (270 ÷ 10). whilst USEFul was able to identify 34.6 usability aspects (mainly violations) per web site (346 ÷ 10) which translates to 28.15% more usability violations being detected.

If a usability expert were to make use of the USEFul framework, then they would be able to detect the green, amber, red and site-specific usability aspects whilst the framework would still report the additional usability violations. This would mean that using the USEFul framework to evaluate the 10 web sites above, the expert would have commented on a total of 477 usability aspects (145 + 125 + 207), that is, an average of 47.7 usability aspects per web site (477 ÷ 10). This can also be interpreted as an increase of 76.67% in the number of usability aspects that the expert evaluator can make per web site.

## 6. LIMITATIONS

As recommended by various researchers [6, 57, 29, 58], the purpose of any tool such as the one being proposed is to provide assistance to human evaluators. Ivory and Chevalier [57] advise that such tools should always be used with caution and one should never completely rely on their results alone. This is because with current technology, it is difficult to develop a tool that can behave like a human and exhibit human attributes such as common sense [16, 58]. This is partially addressed in the USEFul framework through the assignment of the Implementation Level to denote the possible level of automation for each guideline. Still, it was observed that the USEFul framework was not able to handle Nielsen's site-specific recommendations. Such recommendations can be made by a human evaluator through the application of logic, experience and techniques such as grouping guidelines.

Another limitation is the difficulty encountered with incorporating certain guidelines into the rule types tables in the framework's database, particularly because of their abstract nature. At present, the only way to incorporate such guidelines into the USEFul framework is to introduce certain assumptions as recommended by Dix et al. [15] and Vanderdonckt and Beirekdar [59].

Additionally, the proposed guidelines are aimed at evaluating the usability of web sites that have business goals, meaning that these web sites serve to promote and/or sell products and/or services either online via the web site itself or through offline channels [45, 46]. Thus, web sites that do not fall in this category require a different set of guidelines. The framework facilitates this process since it reduces it to incorporating the new guidelines into the database tables without modifying the code.

## 7. CONCLUSION

From the results obtained in this evaluation, it can be concluded that the USEFul framework is very effective at identifying usability aspects that violate usability guidelines. However, bad coding practices can adversely affect the results obtained. The USEFul framework references each guideline that has been implemented in its SQL database to see if the web site has violated it. In the experiments that have been carried out, this factor has enabled it to identify more violations than the usability experts. However, the framework cannot detect what have been classified as red or site-specific violations because it lacks the logic, experience and expertise that an expert in web usability has. In this regard it has been concluded that the framework cannot replace a human evaluator but should be used to assist an evaluator. In fact, the results indicate that using the framework, a usability expert is likely to be able to detect more usability violations

Additional research needs to be carried out to make the framework more flexible so as to be able to implement more abstract guidelines that are currently being classified as having a red implementation level. Currently, the framework can parse HTML and inline and internal CSS code. Therefore, further enhancements that are planned include the ability to parse external CSS stylesheets as well as Javascript parsing since these can considerably affect the way the user sees the web site when rendered through a web browser. So as to overcome the problems with analyzing the content of images in web sites, image processing and Optical Character Recognition algorithms can help in addressing this issue. By implementing these enhancements as well as other algorithms that may be deemed as beneficial, the framework can truly contribute towards mainstreaming web site usability.

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