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An Accented Character-based Captcha System with Usability Test Using Solving Time and Response Time

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Abstract: CAPTCHA is an acronym for Completely Automated Public Turing test to tell Human and Computer Apart. The main purpose of CAPTCHA is to differentiate between human and automated machine during online transaction. Text, image, audio and video are types of CAPTCHAs. However, text-based CAPTCHAs are available in the market in different languages i.e., English, Arabic, Urdu and Chinese but accented character-based text CAPTCHA system namely NAIJACAPTCHA is a newly introduce text-based CAPTCHA developed using Latin characters and accented characters from two Nigerian language: Yorùbá and Igbo. The usability of sixteen accented character-based CAPTCHAs was tested to see if they were suitable for human usage. The usability performance was measured using response time, solving time, accuracy, and success rate. A total of two hundred and twenty-two participants were selected for the study, and 1108 CAPTCHA codes were generated. The response time for Text Distortion with Coloured Background was the fastest, with 1.18×103 ms, while Coloured Texts with No Background (CTNB) had the least response time of 1.09 ms. With a solving time of 2.52×104 ms, Character Fragmentation with No Background was the fastest. The result showed that CTBN's response and problem-solving time is highly promising; as a result, its website application for authentication during online transactions to distinguish between humans and machines will be simple for human beings to solve and user requests will also be swiftly attended to. Lastly, the security aspect of the developed NAIJACAPTCHA will be looked into determine its vulnerability.

Index Terms: Solving Time, Response Time, Usability, Text-based CAPTCHA.

1. Introduction

The Completely Automated Turing Test to Tell Computer and Human Apart (CAPTCHA) is one example of a dynamic authentication technique used to determine whether a user is a human or a computer programme using a digital device, such as a computer, or an electronic service, such as an e-commerce website. [1]. A user must enter a string of text into a security programme to confirm that they are an actual human being. [2]. The advantage of a CAPTCHA system is its capacity to distinguish between a genuine human user and a computer programme robot. Users of computers place a high value on usability since it is essential to productive interactions and participation. Its key component depicts the user's interaction with the computer to accomplish some tasks. Still, the ability of humans to process information is still constrained [3].

Usability, security, and practicality can be categorized as the desired features of a CAPTCHA [4]. The ease with which computer users can solve the CAPTCHA is closely related to the usability factors. The aforementioned perspective, which is user-centric, is therefore the core focus of computer users.

However, Arabic, Hundi, Chinese, and other alternative languages have been proposed and used to make the CAPTCHA system more robust; easy for humans to solve and difficult for automated machines to break [5, 6]. Although, Latin characters are still primarily used in developing text-based CAPTCHAs schemes. Although English is the official language of Nigeria, the country also has a large Yoruba, Igbo, and Hausa speaking population. Numerous Nigerian languages utilize characters with accents. In our most recent paper, the NAIJACAPTCHA text-based CAPTCHA system was developed utilizing characters from two different Nigerian languages. (Yorùbá and Igbo) to enhanced and optimized the existing text-based CAPTCHA system.

The text-based CAPTCHA's security is strengthened by the inclusion of more characters with or without Latin characters, making it less susceptible to bot assaults. However, if the user is unable to escape the CAPTCHA, the solution becomes more challenging. As a result, it makes the CAPTCHA less usable. However, from the perspective of usability, the addition of these new characters strengthens the text-based CAPTCHA's security, which is crucial for CAPTCHA users and programmers. As a result, [7] highlighted how the usage of HCI features such the touch screen enhances CAPTCHA usability. The study proceeded on demonstrating that high usability, high security, and independence factors should be considered while aiming for the most effective text-based CAPTCHA. [8] assert that usability and security are two factors that should be taken into account while creating any form of CAPTCHA. Our study focuses on the usability aspect of our developed NAIJACAPTCHA to determine its simplicity and solvability by human. The objectives that follow; conducting a usability test and determining the user's solving time; system response time; user's success rate and accuracy will be implemented on the developed NAIJACAPTCHA text-based CAPTCHA type in order to accomplish this goal.

2. Related Works

A few research have recently looked into the CAPTCHA's usability aspects. In order to achieved some of the objectives of this research the following work was reviewed. The work of [4] was critically looked into which addressed the issue of employing an acceptable CAPTCHA design from the user's point of view, this was one of our main objectives by conducting a usability test on our developed NAIJACAPTCHA to determine how easy the system is during user's interaction with the system. According to the authors, the tested CAPTCHAs have success rates ranging from 70% to 87%. They also discovered the CAPTCHA time-out issue, which the users may find very interesting. This pioneering CAPTCHA usability study lacks a broad perspective. Additionally, a larger study on the usability of the CAPTCHA was carried out on a group of 24 computer users [9]. Twelve of the twenty-four participants were in the older group (aged 50–56), while the other participants were in the younger group (aged 23–24). However, the relevance of this work to ours was we both make use of human as users and age was also considered. Only the text-based CAPTCHA, which might include various text distortions, was taken into account. The results' analysis showed that the participants' response times and error rates varied significantly between the two age groups. The outcomes also demonstrated that response time and error rate are significantly influenced by the distortion type. Nevertheless, only a very small portion of the population took part in the experiment.

A usability experiment was conducted by [7] via asking 30 users 43 questions. The users were classified into four age groups: (i) those under the age of 5 to 12, (ii) those between the ages of 12 and 18, (iii) those between the ages of 18 and 60, and (iv) those above 60. Essentially, it was an analysis based on what people observed online. The findings demonstrated that the youngest group lacked the expertise and knowledge necessary to correctly solve a CAPTCHA. Additionally, just 5.13% of the oldest group's participants had a probability of completing the CAPTCHA.

The rate for the second-youngest group was 17.95%. With a rate of 76.92%, the third group was the best. They also assessed at the groups' suitability for the text-based CAPTCHA. With a percentage of 31.40, the text-based CAPTCHA was the one that was best suited for the largest demographic of Internet users between the ages of 18 and 60. Additionally, users' satisfaction with text-based CAPTCHAs was declining as a result of continuing integration of sophisticated features.

In [10], one of the largest CAPTCHA usability tests is presented. The need to develop CAPTCHA types that are more user-friendly served as the study's driving force. In that regard, two distinct tests were carried out. There were 131 participants in the first experiment. The cognitive preferences of users for verbal (text) and picture CAPTCHAs were

investigated. There were 125 participants in the second experiment. While solving the text-based and image-based CAPTCHAs, it tested the users' processing speed, regulated attention, and working memory. Analysis of the acquired results showed that while developing more user-centric CAPTCHA variants, user individual variations should be carefully taken into account. Students made up the population sample because they are a young age group. As a result, the results obtained are not sufficiently general. Additionally, the eligibility of a user for a text-based or visual CAPTCHA depends on the user's classification as a verbal or visual user based on their cognitive traits.

The usability of the text-based CAPTCHA was also examined by [11]. In this study, association rule mining was used to analyse how the co-occurrence of typical demographic characteristics affected the response time to the CAPTCHA. A population of Internet users who answered the text-based CAPTCHA on a laptop were the subjects of the analysis. The image-based CAPTCHA that was completed on a laptop was the subject of a similar investigation [12]. Finally, [11-16] used statistical analysis to examine the usefulness of various CAPTCHAS in terms of the dependence of the CAPTCHA response time from individual demographic characteristics. Nevertheless, the selected population was required to solve various CAPTCHAS on a laptop.

According to several research [17,18], basic text-based CAPTCHAs offer better usability and can also be resolved by bots that use OCR techniques. As a result, text-based CAPTCHAs with intricate textures behind the text are always getting better, making it challenging for machines to solve them within a set amount of time. Therefore, it is crucial for usability to test the user's response (time) to a particular text-based CAPTCHA.

The design of handwritten CAPTCHA image using Arabic characters was done by [19], whereby each user is requested to select the joints between Arabic letters once the image is generated, the user is asked to type the letters shown in the image. This experimental study compares the generated images in terms of security and usability for mobile device applications.

A text-based CAPTCHA in the Hindi language was designed by [20], the author was motivated using Hindi language because it was the 4th spoken language in the world. The length of the developed Hindi CAPTCHA varies from 5 to 8 characters with a combination of five different segments. Two versions of the proposed CAPTCHA were generated. During usability test, 1200 CAPTCHA samples were generated from each version with 60 participants. 90.67% and 62.34% recognition accuracy for version 1.0 and version 2.0. The average time to solve a single image was about 10.13 seconds and 13.5 seconds for Version 1.0 and Version 2.0, respectively. This work is similar to our work, but we are focusing on the usability test of the developed CAPTCHA system using our local languages.

3. Preliminary Concepts

The research work was experimental in nature. The quantitative approach was used in carrying out the usability study of the developed accented character-based text CAPTCHA types. To accomplish the objectives as previously stated, the usability tests was conducted in a controlled software laboratory of Federal College of Animal Health and Production Technology Moor Plantation, Ibadan (FCAH&PT). Two hundred and twenty (220) students participated in the experiment. Ages of the students, both male and female, ranged from 18 to 25 years. The participants were instructed to recognize and input several kinds of CAPTCHA codes via a web interface during the real test and submit the characters shown in five randomly produced CAPTCHAs. After each CAPTCHA result has been submitted, the solving time and the response time for solved and unsolved CAPTCHA codes were recorded. The success rate and the accuracy of the solved CAPTCHA types were also determined. This can be mathematical represented as follows:

$$\text{Sr} = Number\ of\ successful\ attempts \times 100 \div Number\ of\ total\ occurences$$

$$\text{A} = number\ of\ successful\ attempts \div total\ number\ of occurences$$

Where Sr = Success rate

A = Accuracy

The developed accented character-based CAPTCHA system was evaluated using the following performance metrics:

- Response Time: this is the time it takes for the user to reply to the CAPTCHA challenge.
- Solving Time: this is the period it takes the user to respond to the challenge posed by the CAPTCHA system
- Success Rate: this is the percentage of successful CAPTCHA code entered correctly over the total number of CAPTCHA code generated for a CAPTCHA type.
- Accuracy: this shows the ratio of the number of CAPTCHA code correctly solved by humans or bots versus the total CAPTCHA code generated.

4. Experiments

The users were given information during the usability trial that will help them get an accurate result. Among the details offered are:

- The character code must have a length of exactly five (5) characters. The user must restart the system if it displays fewer than five characters or more.
- There must be an accent on at least two of the generated characters.
  After validation, the system must show if an attempt was successful or unsuccessful along with the solving time and response time.
- The database must save the solving time and response time.

However, analysis of variance (ANOVA) was used to determine the average solving time and response time for each accented character CAPTCHA code generated. Because the statistical analysis involves various groups, the statistical formula ANOVA is applied. The usability results were represented using algorithm, images and tables as stated thereafter.

Algorithm 1: Accented Character Response, Solving and Matching algorithm
Step 1: Display CAPTCHA code
Step 2a: Determine if user has started to input
Step 2b: If Yes, determine start time
Step 2c: If No, wait for user input
Step 2d: If User presses Enter key, take as end of input. Take as end time of input
Step 3: Check if the user input is equal to generated accented characters:
Step 4: If YES
Step 4.1: Calculate the Response and Solving time
Step 4.2: Save time to the database
Step 4.2 Redirect to a page where it displays
success message
//if NO //
Step 5: Else:
Step 5.1: Calculate the Response and Solving time
Step 5.2: Display an Error message to the user
Step 5.3: end loop
Step 6: Go to Step 1

The algorithm shows system and user's interaction as stated in steps 1-2, step 3 checks the correctness of user's input while steps 4 and 5 show the effect of response and solving time.

Five samples of the sixteen other accented character types in [21] are shown in Fig. 1. The samples indicate the accented character text CAPTCHA type, with the lowest response times, solving times, accuracy, success rates, and number of occurrences among the sixteen CAPTCHA types. The confirmation of this can be seen in Tables 1, 2 and 3 respectively.

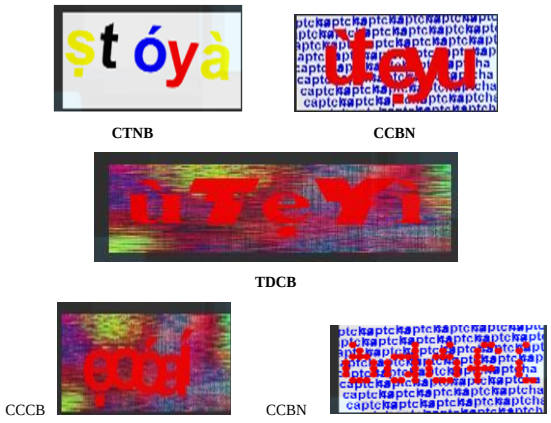

Fig.1. Samples of accented character text CAPTCHA types used during usability test

System's response to user's request during usability test was displayed in Fig. 2. The figure shows the software keyboard which the user used to input the challenge pose, the CAPTCHA code that needs to be rewritten, and the dialogue box where the user will enter his or her response.

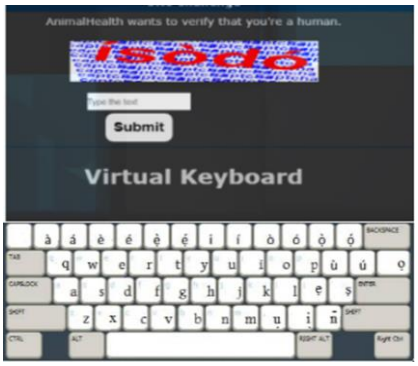

Fig.2. User' interaction with the system

Table 1. Number of occurrences of accented CAPTCHA types in usability test

	CAPTCHA Types	Acronyms	Number of Occurrences	%
1	Character Collapse No Background	CCNB	48	4.33
2	Character Collapse Background Noise	CCBN	48	4.33
3	Character Collapse with Coloured Background	CCCB	44	3.97
4	Character Collapse with Random Lines	CCRL	45	4.06
5	Character Fragmentation No Background	CFNB	69	6.22
6	Character Fragmentation with Background Noise	CFBN	51	4.60
7	Character Fragmentation with Coloured Background	CFCB	61	5.51
8	Character Fragmentation with Random Lines	CFRL	45	4.06
9	Coloured Texts No Background	CTNB	157	14.17
10	Coloured Texts with Background Noise	CTBN	129	11.64
11	Coloured Texts with Coloured Background	CTCB	53	4.78
12	Coloured Texts with Random Lines	CTRL	110	9.93
13	Text Distortion No Background	TDNB	89	8.03
14	Text Distortion with Background Noise	TDBN	59	5.32
15	Text Distortion with Coloured Background	TDCB	51	4.60
16	Text Distortion with Random Lines	TDRL	49	4.42
	TOTAL		1108	100

In the usability examination, Table 1 showed the CAPTCHA types together with their acronyms, the total number of each type's occurrences, and the percentage of each type's occurrence. The result of the study reveals that CCCB had the lowest percentage of occurrence and CTBN had the greatest.

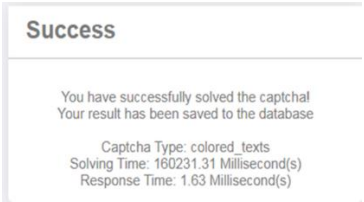

Fig.3. Participant's metric performance

Fig. 3 depicts the user's successful attempt during the usability test; it shows the type of CAPTCHA they solved, the user's solving time and system' response time.

The CAPTCHA type, its acronym, the number of successful and unsuccessful attempts, and its success percentage are all displayed in Table 2. According to the results, CCCB has the lowest success rate and CTNB has the highest.

Table 3 included data on the frequency of each CAPTCHA type and the average time required to solve it. According to the results, CFNB had the fastest solving time, while CCBN had the slowest.

In Fig. 4, the information regarding the typical response time of the correctly completed CAPTCHA types was represented graphically.

Fig. 5 demonstrates the accuracy of the responses given by each participant, with CTNB and CCCB having the highest and lowest accuracy, respectively.

Table 2. Success rate for accented CAPTCHA code types

	CAPTCHA Types	Acronyms	Successful	Unsuccessful	Success Rate
1	Character Collapse No Background	CCNB	28	20	58.33
2	Character Collapse Background Noise	CCBN	32	16	66.67
3	Character Collapse with Coloured Background	CCCB	22	22	50.00
4	Character Collapse with Random Lines	CCRL	28	17	62.22
5	Character Fragmentation No Background	CFNB	44	25	63.77
6	Character Fragmentation with Background Noise	CFBN	30	21	58.82
7	Character Fragmentation with Coloured Background	CFCB	48	13	78.69
8	Character Fragmentation with Random Lines	CFRL	30	15	66.67
9	Coloured Texts No Background	CTNB	138	19	87.90
10	Coloured Texts with Background Noise	CTBN	111	18	86.05
11	Coloured Texts with Coloured Background	CTCB	38	15	71.70
12	Coloured Texts with Random Lines	CTRL	85	25	77.27
13	Text Distortion No Background	TDNB	60	29	67.42
14	Text Distortion with Background Noise	TDBN	32	27	54.24
15	Text Distortion with Coloured Background	TDCB	37	14	72.55
16	Text Distortion with Random Lines	TDRL	29	20	59.18

Table 3. Average solving time for participants

	CAPTCHA Types	Acronyms	Number of generated codes	Solving time (milliseconds)
1	Character Collapse No Background	CCNB	48	39087.98
2	Character Collapse Background Noise	CCBN	48	126723.50
3	Character Collapse with Coloured Background	CCCB	44	70366.74
4	Character Collapse with Random Lines	CCRL	45	50121.01
5	Character Fragmentation No Background	CFNB	69	25214.20
6	Character Fragmentation with Background Noise	CFBN	51	27222.68
7	Character Fragmentation with Coloured Background	CFCB	61	65608.89
8	Character Fragmentation with Random Lines	CFRL	45	49060.23
9	Coloured Texts No Background	CTNB	157	76447.79
10	Coloured Texts with Background Noise	CTBN	129	43572.45
11	Coloured Texts with Coloured Background	CTCB	53	61163.39
12	Coloured Texts with Random Lines	CTRL	110	47121.37
13	Text Distortion No Background	TDNB	89	50628.35
14	Text Distortion with Background Noise	TDBN	59	34075.37
15	Text Distortion with Coloured Background	TDCB	51	58703.04
16	Text Distortion with Random Lines	TDRL	49	47345.16

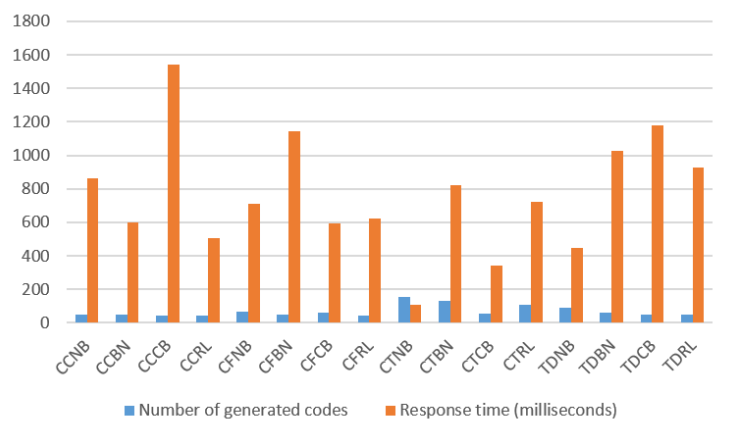

Fig.4. Graphical representation of average response time

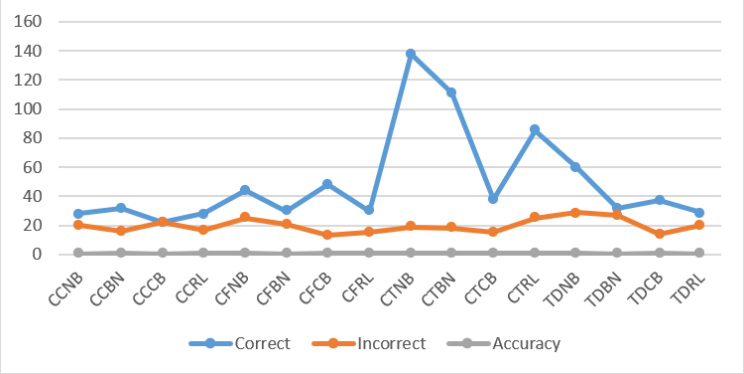

Fig.5. Graphical representation of accuracy of the responses

5. Discussions

The usability test was conducted using 1108 CAPTCHA codes. The length of the developed NAIJACAPTCHA does not exceed five characters with at least two accented characters. Two performance metrics were used to evaluate the CAPTCHA types. The experimental approach of testing the usability performance of NAIJACAPTCHA with response and solving time was supported by [20-25] to determine the efficiency and effectiveness of text-based CAPTCHA system. The result from their studies show that the existing CAPTCHA system has some difficulties in solving the current CAPTCHA due to some dominant features such as color, distortion and background introduced in the design of the CAPTCHA system. The effect of these features determines the number of occurrences of each NAIJACAPTCHA which lies within the same range of 44-90, except for three types whose values were higher than 100. This was confirmed by the work of [26]. The success rate for participants indicates that the CAPTCHA codes generated are human readable with appropriate responses through the software keyboard provided. Participant were able to solve the CAPTCHA challenge posed because all responses took milliseconds. The usability results indicate that the level of accuracy is not affected by the knowledge of the language. [27]

6. Conclusions

The vulnerability of the current text-based CAPTCHA to attack will be significantly reduced with the addition of accented characters to the existing text-based CAPTCHA. In contrast to other CAPTCHA system, which was developed using Arabic, Chinese, Korean, etc. languages, the developed system is not language biased and may be used by any web service provider and users, regardless of the country.

Moreover, the effectiveness and precision of all the newly developed CAPTCHA systems were commended. However, the deployment of NAIJACAPTCHAs into website will help in distinguishing human from machine and also prevent the intervention of an automated machine. In the near future, the security feature will also be taken into account in evaluating the strength and robustness of NAIJACAPTCHA.

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