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Human-Centric Audio CAPTCHA for the Visually Impaired: Usability and Efficiency Evaluation

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ABSTRACT

Telling humans apart from automated bots has long been a frustrating challenge for visually impaired users, who find themselves locked out of ordinary web services by CAPTCHA systems built almost entirely around vision. Distorted text, image grids, and moving puzzles offer little to someone who cannot see them clearly, or at all.This paper presents a CAPTCHA system built around a different approach: rather than asking users to see something, it asks them to hear and then speak. A word is drawn at random from the system's database, played aloud to the user, and the user repeats it. A speech recognition engine then compares what was spoken against what was generated, completing the verification without any visual interaction. The design rests on a straightforward observation fluent, natural speech remains something humans do far more organically than machines and the two-step process of listening then responding adds a meaningful layer of resistance against automated attacks. The system was tested alongside currently deployed CAPTCHA solutions, with forty-seven participants spanning four categories of visual impairment: total blindness, partial blindness, night blindness, and half blindness. Results showed a 70 % rise in verification success rates and a 95 % reduction in access time compared to existing systems. Participants who previously required sighted assistance were able to complete verification independently using only their hearing and voice. Beyond accessibility, the spoken-word database collected during testing opens a path toward future Arabic-language speech-to-text development, allowing visually impaired individuals to contribute to rather than simply be accommodated by the technical projects that shape their digital lives.

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Introduction

CAPTCHA verification code is a check mechanism that web application users must pass in order to use the website services, the main goal of this mechanism is to verify that the user who is interacting with the website content is actually a human and not a machine or a software code that is automatically interacting with the website, subsequently assisting in preventing attacks of hackers, information thieves and spam applications which are programmed to repeat a certain pattern [Abdullah et al., 2022].



Figure (1): Examples of a group of vocal verification codes systems.

The basic goals for our creative CAPTCHA verification cod technology is (1) provide better quality of internet services to visually impaired users who cannot access the services protected by verification codes, (2) presenting a new method for a technology that participates in actively integrating visually impaired persons in the technical projects with their non-challenged beers , for example when participating in technical projects accompanying the newer reCAPTCHA verification cod system. As we mentioned before, this project is especially targeting the visually impaired persons by building a new visual verification system that depends on the hearing capabilities of the users who suffers difficulties in vision of the content and answering the question through direct speech by pronouncing words not letters. The second part of the paper contains more design details of the new

proposed CAPTCHA verification code system. In that part also data collected on CAPTCHA and reCAPTCHA verification code systems for a number of internet sites and their design and interactivity levels among visually impaired persons and the levels of ease for successfully passing the checks, in the third part a narrative on the alternative solutions and the new design of the CAPTCHA verification code system, the fourth part explains the potential of integrating the proposed new technology with internet sites. The fifth part covers the checks and discusses their results while the sixth part covers the recommendations and the seventh covers the future works.

Development of the recent CAPTCHA systems and their related accessibility

All CAPTCHA verification codes systems 'companies depend on common basic steps to develop this technology, these steps made it harder for the visually impaired users to interact with this technology, we can sum the steps in two, the first is to know the procedure through which human beings analyse data like sounds and shapes[Hossen & Hei, 2022]. The visual verification system developers do not take into their account the visually and mentally impaired users, although knowing how the machine or computer analyses data, as it follows a number of orders and instructions coded in a specific programming language , so if one of these instructions fails then the computer becomes unable to continue the data analysing process and stops, this is a pivotal point for the visual verification systems analysts considered as a weak point when establishing CAPTCHA code check, Figure (2) shows different types of verification codes, one of the most important failure points in the recent visual verification systems is not being able to cater for the non-functional visually impaired users, like usability, and functionality which is the time consumed by the system to react with the user, and compatibility with other programs or tools used by the visually impaired persons is the second standard or step in designing verification codes systems which depend on not using clear letters and numbers without any distortion on them, because of the fact that several computer programs can identify those letters and numbers through optical character recognition [Wang et al., 2024].

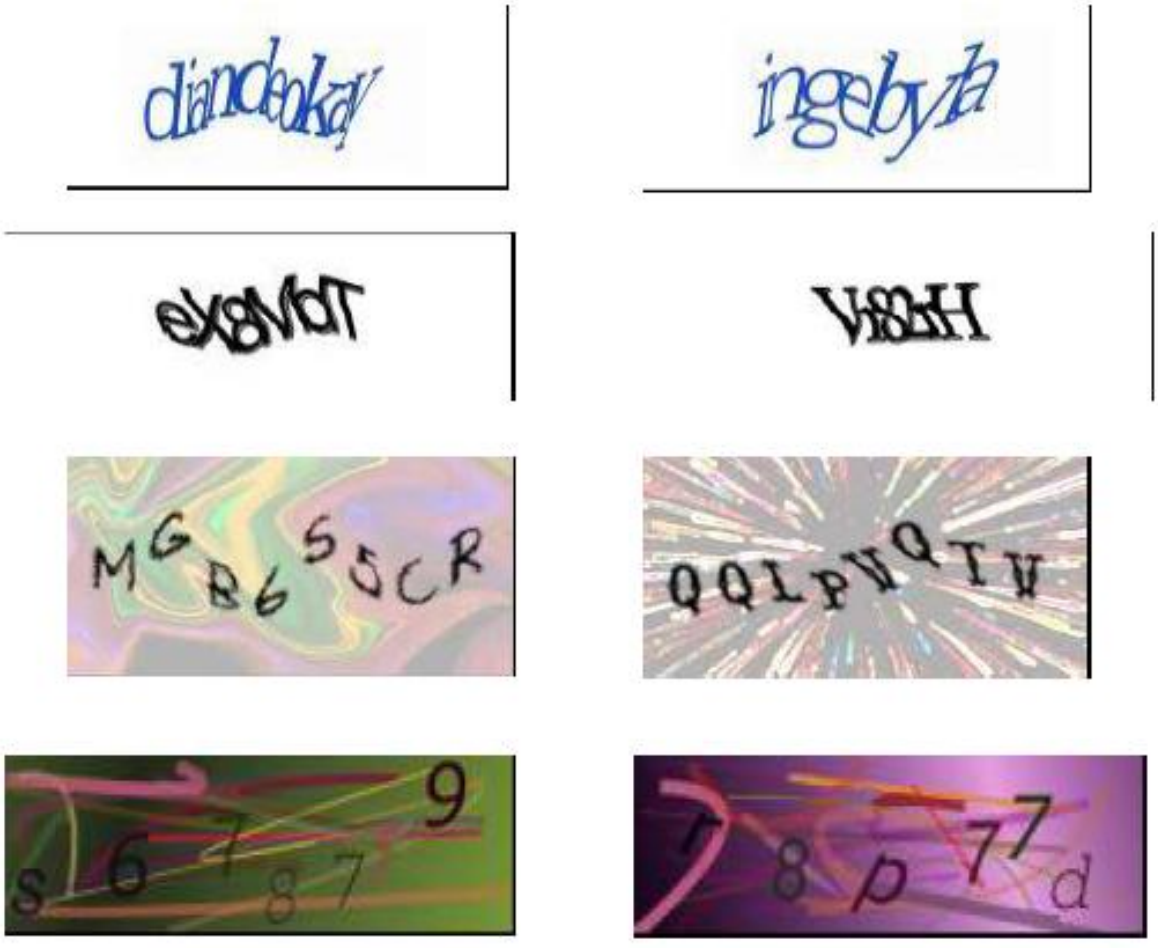


Figure (2): Different types of verification codes (from yahoo, Google, xdrive.com and forexhound.com)

Another basic point in the design of verification codes systems that is the essence of the problem for the visually impaired users and other mental impaired users, is the fact that the system produces shapes or questions and answers depending on a predesigned data base containing those questions and the continuation process to benefit from the website service depend solely on the visual interact and check in the user analysis process, in another meaning the verification process depends on data entered after the visual verification check processes are done by the user and inputting check result is done through a visual interaction as well with the answering box, then the system conduct a comparison for between users' answer and the one stored in the systems' databases, based on the outcome, the user is allowed to continue enjoying the website services or asked to answer again without taking into account changing the visual check method or the interaction between the user and the verification system.

Many of the scientific researches related to the development of verification codes systems as well as the technology development experts recommend that the good and acceptable verification code is the one that is over 80% solvable by the users and less than 0.02% solvable by hacker-programs, and the database should contain no less than 10,000 different choices, otherwise the penetrators may be able to collect all the possibilities and use brut force to break the code, there are also recommendations to use the random generation of numbers and letters making it difficult for bots programs to penetrate the verification codes system, the more numbers means more protection power [Wang et al., 2024]..



Figure (3): A verification code difficult to read even by intact vision users

Invisible access to Internet services protected by CAPTCHA verification codes technology

In this work, a new way of interacting with websites contents is introduced bearing in mind all the different capabilities of users and their accessibility to websites contents including different types of visually impaired users who are suffering from: blindness, partial blindness, colour blindness, visual impairment, night blindness and some mentally impairments affecting users full accessibility to website contents[Fanelle et al., 2020].

A new verification system has been developed depending on the non-impaired organ of the visually impaired user, by replacing the visual interaction with vocal one with the developed verification system.

The new technology depends on only two steps to gain access to the verification code protected Internet services; the steps are:

Listening: listening to the content through earphones.

Speaking: interacting with the content through speech.

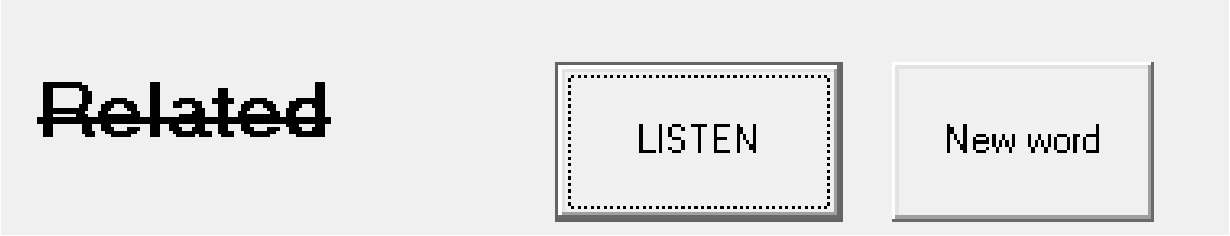


Figure (4): The new CAPTCHA system.

All programming tools of the new verification code technology have alternative vocal content, when passing the mouse pointer over them; the user hears the text content on the button, for the example in Figure (4) when the user passes the cursor on "new word" button, this action is triggers an event which is the user hearing of the phrase "new word" through the computer speakers then the visually impaired user clicks on "new word button", the system produces and displays the script of the new word accompanied with hearing the new word through his machines speakers.

After hearing the word, for example "Sudan" the user is only required to repeat the word and here comes the role of the speech recognition technology which is integrated in our new system, and comparing the vocal instruction produced by the user with the words produced by the system, at this point the verification takes place verifying that the user is not a machine or hacking computer program, and the user is allowed to benefit from the services, and in the case of the system failure to recognize the spoken words of the user, he is required to retry with a new word in a process not relying on visual interaction but rely on the vocal interaction between the system and the visually impaired user Figure (5).

Non-visual accessibility or vocal interaction is our new systems' mechanism to assure the user passing the verification codes questions as well as insuring the prevention of the non-authorized access in case of hacker programs, this adds another security advantage depending on the speech recognition as the system transforms the spoken words by the user who faces suffers visual and mental impairments to text, it worth mentioning here that the speech recognition technology is different from the voice recognition in which the systems have to be trained on a specific speaker as is the case with most desktop recognition programs, but in the speech recognition technology used in our verification system is a broader concept relating to a technology that can recognize the speech without targeting one specific speaker like communication systems which can identify all interacting users' voices.

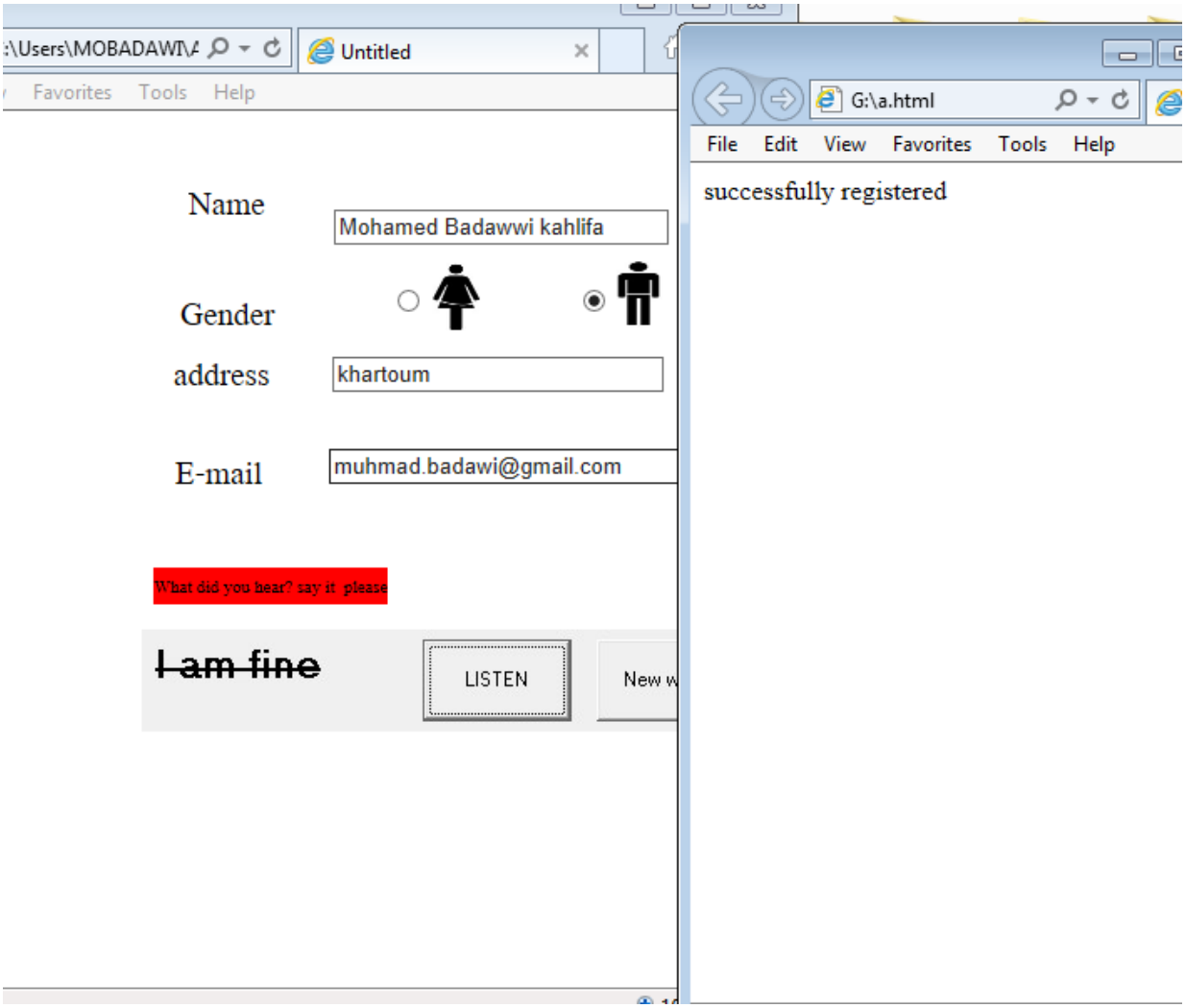


Figure (5): Passing of a blind user of the verification test using vocal interaction in the new verification system.

Integration with the recent internet sites

The advantage of the new CAPTCHA verification system that is presented in this paper is that it be added as a plug-in by the internet sites designers due to the ease in installing in the site. From the programming point of view, the system consists of a set of code lines and link files for the speech recognition and transforming scripts to speech technologies in a compact programming unit to be enlisted in WebPages after specifying the execution location as displayed in Figure (6).

The new system file does not contain instructions to be executed within the clients' data, the websites benefit from the service as website developers make a service request through our application programming interface API.

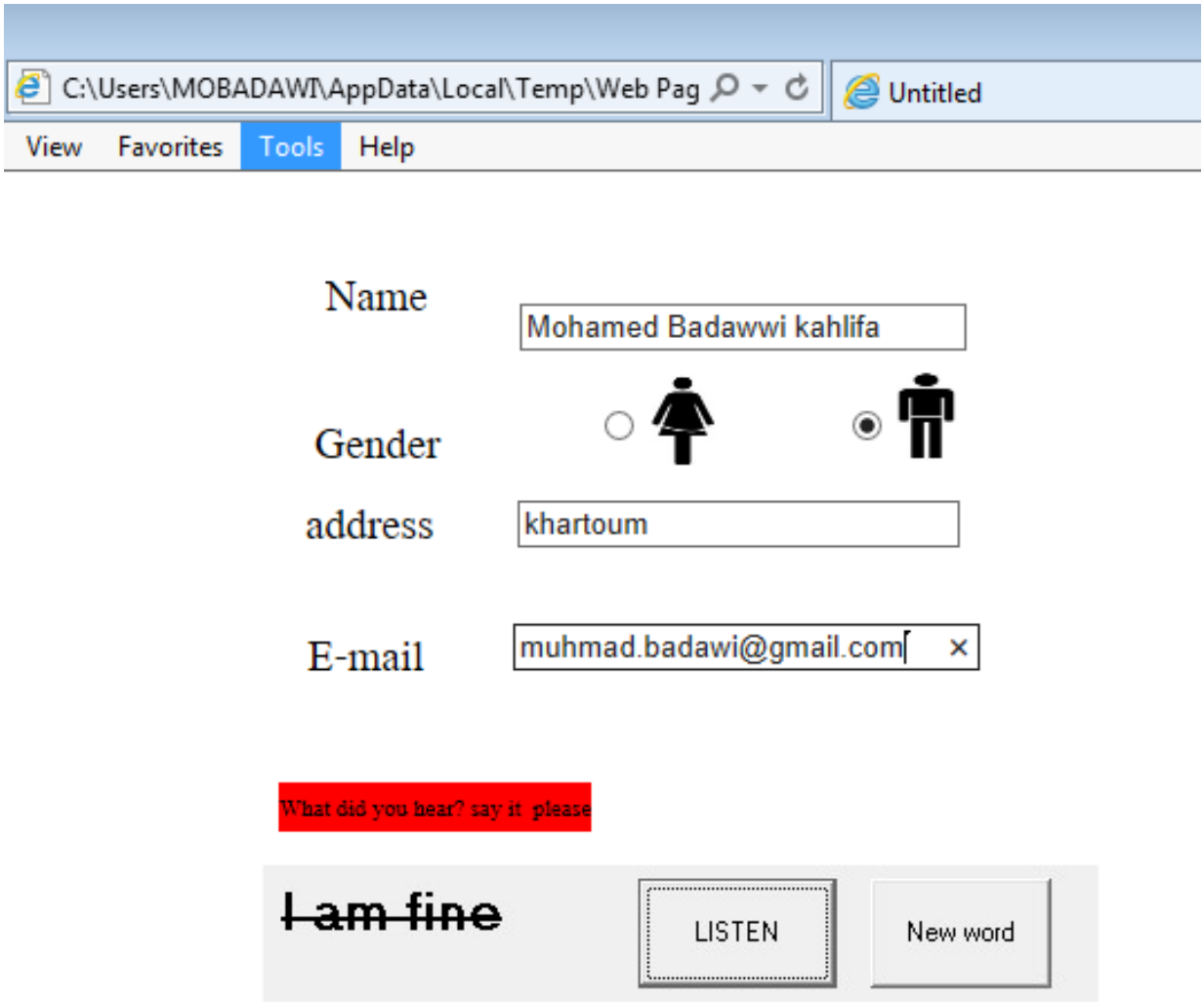


Figure (6): Integration of the new verification code system with websites

Assessment of the recent verification systems and the new system:

Many web services provide vocal verification codes systems as an alternative to visual access. But do these alternatives insure the visually impaired person's alternative tools for the visual interaction. Or we need to produce technical alternatives to allow hearing interaction with the systems depending on the use of intact and not impaired senses.

Here we list the basic principles adhered to by the CAPTCHA visual verification codes in building and developing this technology:

• Easy for the users to find the answer to the verification code.

• Hard for the computer to find the answer.

• Easy to generate alternative codes and assessing the answers.

Depending on these principles we conducted tests on a number of different types of visually impaired internet users, the different types of visual impairments were as follows:

• Totally blind: these are users of websites who suffer from total blindness; we will refer to them with the initials (TB).

• Partially blind: these are users of websites who suffer from partial blindness due to a deficiency in the intactness of the optical nerve of the eye; we will refer to them with the initials (PB).

• Night blind: these are users of websites who lack the ability to see things when moving from a bright place to a darker one; we will refer to them with the initials (NB).

• Half blind: these are users of websites who suffer from half blindness caused by a clot that affects the centre of vision in brain; we will refer to them with the initials (HB).

The table bellow demonstrates the different types of visual impairments targeted in the tests and the numbers of participants

Table (1): Number of participants in the tests.

Type of visual impairment	Reference	Number
Total Blindness	TB	12
Partial Blindness	PB	15
Night Blindness	NB	12
Half Blindness	HB	08

Within the participants in the tests 100% of (TB) users use aiding technologies and screen readers, 20% of (PB) users use programs to assist them in interacting with web applications while the rest does not use any assisting technologies, 1% of (HB) users use assisting technologies and 2% of (NB) users use assisting technologies.

The tests depended on basic standards for the Software Quality Assurance specifically performance related ones, those two factors are Efficiency which means the execution efficiency and is measured by the processing time, the other factor is the usability which takes into account the operability which is the adoption of individual learning strategy where the inability of the user to use the system by himself is unacceptable.

And quality factors related to correctness which is achieved through completeness which is the optimal performance of the system to fulfil biggest number of users' requirements. The tests were conducted on the recent in use verification systems in for verifying users in google.com and facebook.com.

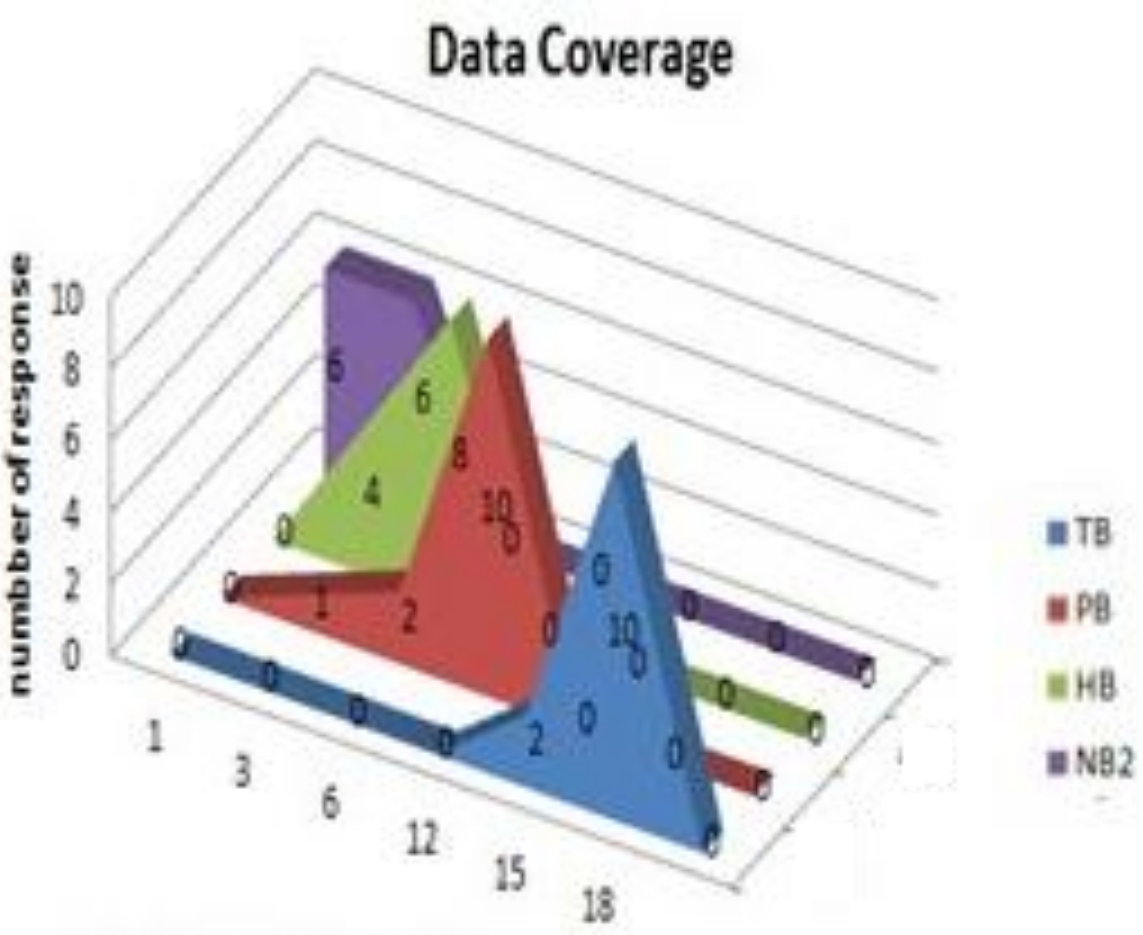
Assessment results of the recent verification systems

This test covered all types of visual impairments (TB, PB, HB, NB) and was aimed at measuring the level of ease of using the recent vocal verification systems and the number of attempts of reloading the page is needed to change the verification system after failure to interact with the system. Figure (7) shows the number of attempts pages were loaded and eventually the amount of data loaded to access one of the email providing services for each impairment separately.

Performance test results

In system performance assessment test, (TB) users who are 12 in total were facing big difficulty in accessing the websites which were protected by verification codes where the operability is close to being nonexistent; they needed to reload the verification codes from 12 to 15 attempts and that after assistance from vision intact persons. Figure (7) shows the ease of using the recent visual verification systems and the number of reloading attempts as well as the number of users giving correct answers, as the reload attempts exceed 3 attempts, the user suffers more in order to access the visual verification code protected site.

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	1	3	6	12	15	18	
TB	0	0	0	0	2	10	
PB	0	1	2	10	0	0	
HB	0	4	8	0	0	0	
NB2	6	6	0	0	0	0	

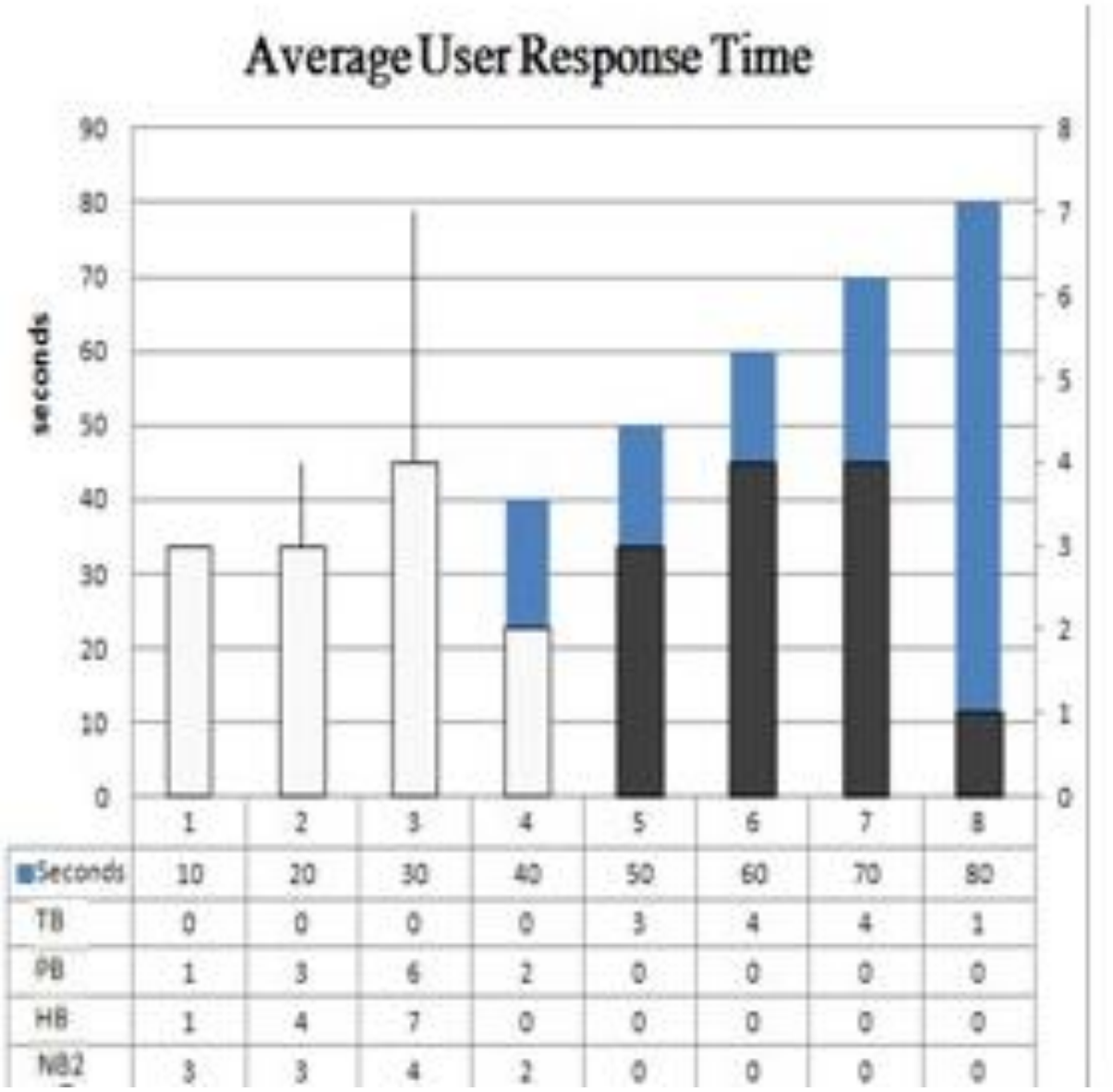
Figure (7): Usability of the recent visual verification systems used by google.com and facebook.com

Among (PB) users who are 15 in number, only one user was able to access the protected page after two attempts of reloading the verification codes questions and 10 users needed 6 to 12 reload attempts. For (NB) users, the maximum number of reloading attempts was 3, while 8 users did not need to reload which exceeds 66% of that group.

Efficiency test results

In efficiency measurement test which is measured by processing time, the results were as follows: Only 4 of the totally blind users were able to access the protected content in less than 60 seconds as demonstrated in Figure (8), we also find that as the visual sense decreases the accessing times to the visual verification codes protected sites increase.

The (NB) users did not face mentionable difficulties to access the visual verification codes protected sites, more than 10 users accessed the content in less than 30 seconds. All (HB) users were able to access the protected content in less than 30 seconds.



	1	2	3	4	5	6	7	8
Seconds	10	20	30	40	50	60	70	80
TB	0	0	0	0	3	4	4	1
PB	1	3	6	2	0	0	0	0
HB	1	4	7	0	0	0	0	0
NB2	3	3	4	2	0	0	0	0

Figure (8): Different access times for users with different types of visual impairments

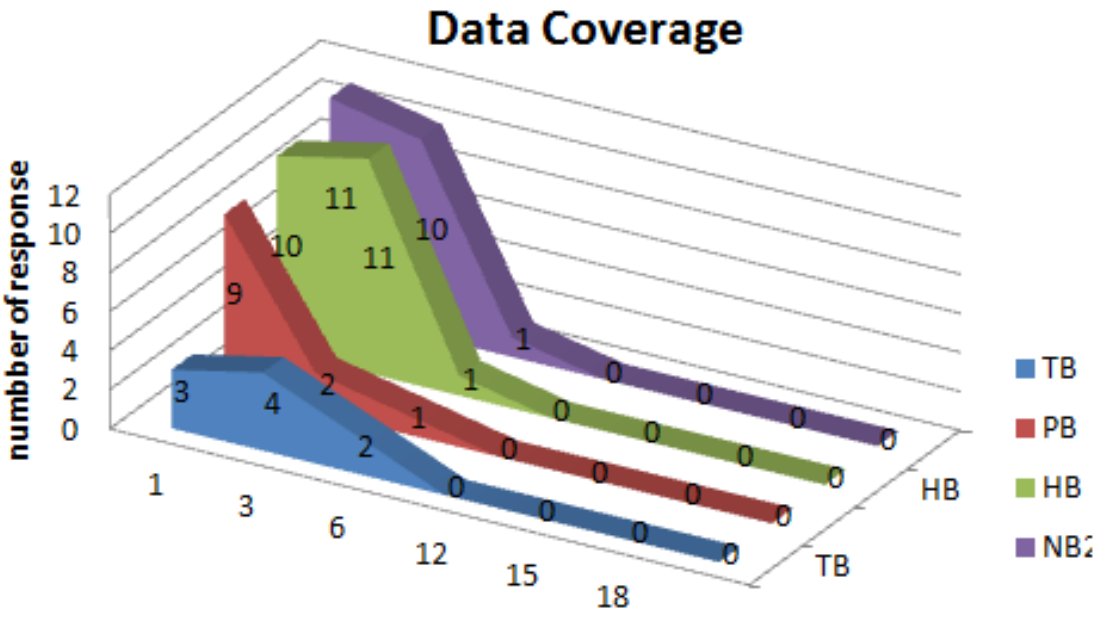
The new CAPTCHA system assessment results:

We reran the above tests on the new verification system shown in picture (4) with the same types of visual impairments and same users and computers. In the usability test which takes into account the operability, the number verification codes questions reloading attempts decreased as seen in picture (9).

Performance tests results:

In systems' performance assessment test, for (TB) users who were 12 in total, the accessibility to the verification codes protected websites increased, as the operability increased after being nonexistent, those users needed less than 9 attempts without the assistance of vision intact persons and without the use of assisting tools "Hearing of verification codes, pronouncing the code through the computer microphone".

3 of the (TB) user did not need to reload the verification questions and reached the protected content from the first attempt, of the (PB) user who were 15 in number, 9 users were able to access the protected page after one attempt, For the (NB) users, the maximum number of attempts was 3 and 6 users did not need to reload making a less than 55% of the group. In picture (9) the usability of the new visual verification system is displayed showing the number of reload attempts and the number of users with correct answers, we find that the number of questions reloads attempts decreases and the operability of the new system scored little change among the different visual impairments.



reload Capatch Questions

	1	3	6	12	15	18	
TB	3	4	2	0	0	0	
PB	9	2	1	0	0	0	
HB	10	11	1	0	0	0	
NB2	11	10	1	0	0	0	

Figure (9): Usability of the new visual CAPTCHA system

Efficiency tests results

In the systems' efficiency test which is measured by the processing time, results were as follows: All users with different impairments (TB, PB, HB, NB) were able to access the CAPTCHA verification codes protected web content in less than 30 seconds. 7 of the (TB) users were able to access the protected content in less than 10 seconds, as Figure (10) shows, different access times for the users with different impairments after using our proposed system, processing time for the users decreased by more than 90%. We find also that with increased vision sense the access time to visual verification codes protected websites decrease. All (NB) users were able to access the protected internet service in less than 8 seconds.

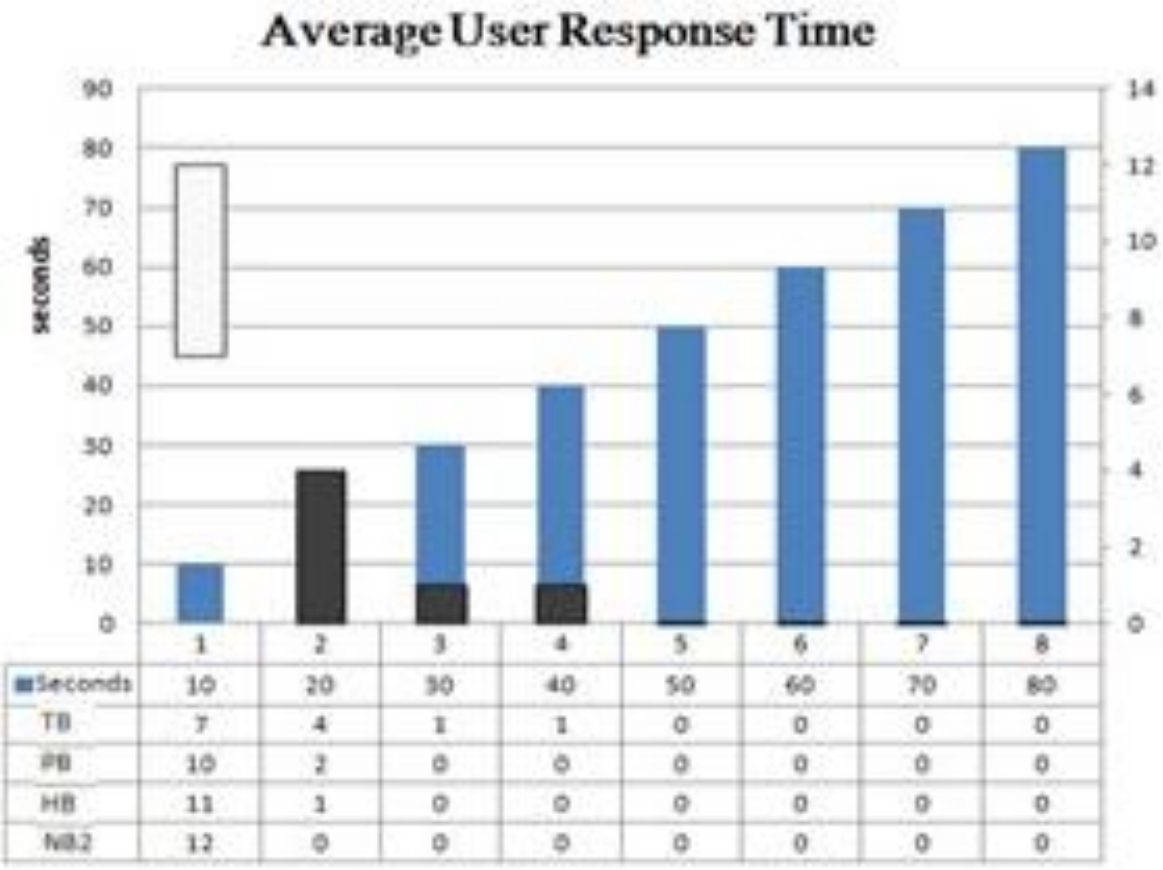


Figure (10): shows the Different access times for users with different types of visual impairments after using our proposed system.

Conclusion and recommendations

Dependence of the alternative solutions and the assisting accessibility technologies and the programming tools used by the visually impaired users on the visual interaction means makes their performance lack the efficiency and the required usability which In completely non-existent. Comparison with the new system that depends only on vocal interaction, we find that the efficiency of the system —the efficiency of execution is high levels in the access time to the CAPTCHA verification codes protected content, displayed in the two diagrams in Figure (8) and (10).

The principle of developing this system that we presented in this paper is based OH the interaction of the impaired user through a non impaired and intact sense of the other user senses. which translated as increase in usability of the CAPTCHA verification codes protected sites in specific and the information technology in general without the need of a costly assisting technology, We find also that the users who are able to visually interact with the systems like the users suffering from night blindness scored an increase in the number of attempts to reload the verification codes questions, all that is explains that as the visual sense of the user is decreased he/she faces difficulties in interacting with the verification systems and the information systems that contain graphic interfaces in general, when building systems dependent only on hearing sensation and vocal interaction of the visually impaired users, we ease the process of engaging them in our technical communities. One of the most important advantages of the new visual verification codes system is the introduction of a new method that eases the accessibility to them in an alternative way for the users with the inability to visually interact and suffer difficulties in vision like colour blindness and vision deficiency and other visual impairments. This method can be depended on in conducting verification processes for the users suffering from mental difficulties to insure a seamless interaction process between them and the internet applications in specific.

Future work

The new technology developed in this work produced a big database of vocal word pronounced in a normal fashion by the participants having different visual impairments during the testing phase, this will participate in the development of technological projects to pave the way for visually impaired persons to participate in the various computing projects, like the development of new reCAPTCHA technologies to produce text to sound transforming technologies in Arabic language and other languages, enabling the visually challenged persons to

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engage in their technical communities more effectively and efficiently.

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