# Engineering Graphical Captcha and AES Crypto Hash Functions for Secure Online Authentication

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## ABSTRACT

Password alone is currently not trusted for user online authentication and security as threats from hackers continue to grow, requiring highly efficient defense safeguard protection against unauthorized users. Therefore, CAPTCHA techniques came into the picture as an automated assistance to distinguish between humans and robots. The CAPTCHA has several applications in the online security domain requiring to be merged with encrypted hash function benefitting from the facility of the graphical password schemes. This paper proposes engineering an authentication technique using graphical CAPTCHA with an AES encrypted hash password to maintain applicable security accessing systems. We propose three layered security system that joins highly efficient security mechanisms to avoid users' stress of entering password many times or different other hectic routines in order to save account accessing.

**Keywords:** access control; authentication; captcha; cryptography; encryption; hashing.

## INTRODUCTION

The user authentication of online systems plays an important role in the protection of the personal sensitive information from unauthorized hackers (Alanizy et al., 2018). It also prevents systems from losing the classified data which is becoming essential for block-chain applications (Altalhi & Gutub, 2021). Nowadays, the normal technique used for authentication is via secure passwords becoming vulnerable to denial of service attacks as well as password guessing techniques (Al-Shaarani et al., 2020). To mitigate these user authentication attacks, researchers propose involving a *Completely Automated Public Turing tests to tell Computers and Humans Apart* (CAPTCHA) approach, that prevents computer generated program to access the system (Kheshaifaty & Gutub, 2020). There are three types of CAPTCHA common easy tools used, based on image, sound, and text schemes. Interestingly, text-based CAPTCHA is the most widely used scheme (Kolekar & Vaidya, 2015), considering text language community practicality (Gutub et al., 2010), as shown in Figure 1.

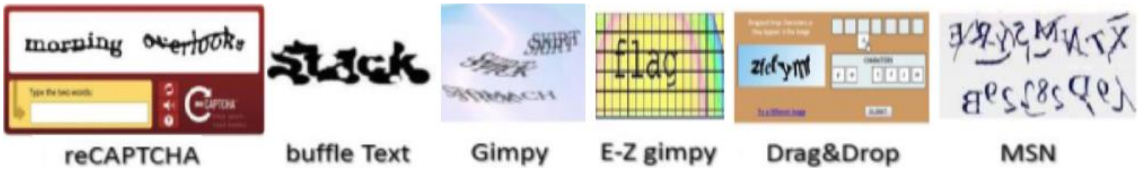


**Figure 1.** Graphical text CAPTCHA

This engineering research proposes utilizing Password Guessing Resistant Protocol (PGRP) to control the online password predicting attacks and the brute force attacks (Ahmed et al., 2016). The method is barring sign-in attempts from undesirable web servers similar in principle to trusting counting-based secret sharing (Gutub et al., 2019) which is advanced for proper authentication via M-Blocks partitioning (Gutub & Al-Qurashi, 2020). The PGRP includes two interfaces, namely graphical-user interface (GUI) and character-based interface, which is found common for most IoT technologies (Shambour & Gutub, 2021). This work adopted the estimation attack against ten popular real-world captcha schemes provided by google.com pretending to break them. Our study further compared the security, investigating the attacks with two common methods of eight captcha (solving services) and nine online image recognition services. The results of analysis proposed our 3-layer scheme to combine captcha with hash and encryption following the published 2-level stego-crypto security combination (Alkhudaydi & Gutub, 2021). Our proposal is based on the distance, the process of zooming, transverse displacements, and twisting characters, which all can be closely linked to capture Captcha image styles.

## LITERATURE REVIEW

As part of the literature review, different methodologies based on secure access were analyzed in order to determine loopholes to be addressed. For example, Vaithyasubramanian (2016) notes that audio CAPTCHA used to prevent auto brute force attempts that can be helpful for visually impaired people. Audio security is helpful in current applications as other multimedia get corrupted or less useful (Al-Juaid & Gutub, 2019). This research audio CAPTCHA suffered noise of speakers, which matched the background noise, and found having finite set of vocabulary reducing its security. Other CAPTCHA schemes used puzzle-based manipulation, which involved puzzles, such as Cascading style sheet, JQuery, and HTML (Ali & Karim, 2014) or any complex image-based authentication (Al-Roithy & Gutub, 2021). The puzzle-based CAPTCHA showed authentication testing, but requested puzzle-based widget to provide support for installing web information. Therefore, Cui et al. (2010) used CAPTCHA to prevent malicious advertisement attacks on the web by multi-layer CAPTCHA techniques. Their work bonded vision theory to be easy for human identification in an optimization structure. Statistical function variance was employed for the mitigation of the attacks in a complex manner, as found appropriate for complex applications such as medical and airline services (Alsaidi et al., 2019).

Since CAPTCHA can be categorized on OCR relation, Kaur (2016) proposed non-OCR Math CAPTCHA based on Boolean algebra. This authentication technique showed good attack control rate, but was also found aligned to a complex database that cannot be generalized to many other applications. Similarly, Althamary and El-Afy (2017) proposed accessing methodology based on passkey with a combination of user password and the characters of CAPTCHA. Although, the results of this technique show remarkable gain by resolving attack issues of key logger, phishing, and password guessing, it is unfavored because of its limitation on the agreement with the user.

Kulkarni and Malwatkar (2015) presented graphical CAPTCHA method that utilizes image processing along with AI techniques. The research provided multiple image challenges to mitigate the shoulder surfing security issue, as found very suitable for desktop application security. However, the drawback of this scheme is in utilizing space for multiple passwords involved by the user running every login session. Lv et al. (2016) notes that English language-based CAPTCHA is easy to understand compared to Chinese CAPTCHA that is more complex to solve. The distortion and noise have been resolved by involving conventional neural network (CNN) approaches resulting in accuracy improvement, but with complex designing. Furthermore, Zhang et al. (2017) argues linking to segmentation to improve CAPTCHA recognition. Their work coded vertical projection to the segmentation of the characters, but found reduction in its security reliability.

Tirthani and Ganesan (2014) proposed user authentication based on sharing unusual keys to prevent DOS attacks. The session of key generation is done through Diffie-Hellman key exchange scheme. Similarly, Alta vista website adopted a private captcha system to differentiate between computer and humans. Relatively, Malutan and Grosan (2015) introduced two new schemes of graphical passwords abbreviated as COSS and CODP schemes, which reduce the chances of shoulder surfing attacks. This method shows strangest entropy bit as compared to other schemes since it generates strong passwords by using set of questions and answers.

Table 1 summarizes the performance of recent related researches considered most relevant to the evaluation of our study. The table assigned notations to be used within this paper for precise symbolization, i.e. throughout the work. The brief comparison links the cost, productivity, user satisfaction, and security quality to further justify the need for our 3-layer authentication research.

**Table 1.** Performances of relevant researches showing its notation for using within this study.

| **Study** | **Research Paper Notation** | **Performance Evaluation Criteria** | | | |
|---|---|---|---|---|---|
| | | **Cost** | **Productive** | **Customer Satisfaction** | **Quality** |
| (Vaithyasubramanian, 2016) | V-2016 | High | Good | Yes | OK |
| (Ali & Karim, 2014) | A-2014 | Moderate | Good | Yes | OK |
| (Cui et al., 2010) | C-2010 | High | OK | No | Poor |
| (Kaur, 2016) | K-2016 | High | Good | Yes | OK |
| (Lv et al., 2016) | L-2016 | Moderate | Low | No | Poor |
| (Zhang et al., 2017) | Z-2017 | Moderate | Low | No | Poor |
| (Ahn et al., 2003) | A-2003 | Moderate | Low | No | Very poor |
| (Tirthani & Ganesan, 2014) | T-2014 | Moderate | Low | No | Poor |
| (Chen et al., 2014) | C-2014 | High | Good | Yes | High |
| (Liao et al., 2005) | L-2005 | Moderate | Ok | Yes | Ok |
| (Juang et al., 2008) | J-2008 | Low | Good | Yes | High |
| (Das et al., 2007) | D-2007 | Moderate | Ok | No | Poor |
| (McLoone & McCanny, 2003) | M-2003 | Moderate | Ok | Yes | Ok |
| (Merler & Jacob, 2009) | M-2009 | Moderate | Good | Yes | High |
| (Gossweiler et al., 2009) | G-2009 | High | Ok | No | Ok |
| (Zhang et al., 2019) | Z-2019 | High | Good | Yes | High |

The study showed that most of current applicable researches utilized two-layer authentication (Al-Ghamdi et al., 2019.), and some unacceptable single authentication (Al-Nofaie & Gutub 2020), were all considered to be vulnerable in today's advancing IoT and AI technology (Alassaf & Gutub, 2019.). Therefore, our proposal targeted 3-layered authentication research to provide practical accessing trustful security.

In this paper, the engineering methodology measured directional based graphical password technique to be used to modify pass faces scheme with direction image. Shoulder surfing proof authentication has been shown because the user would not click on their picture directly in this process. Since the hashed value is immutable, the algorithm of probability is used. This algorithm keeps the right, left, top and bottom values of the photos that have been clicked. According to their directions the image will be combined and all values are compared with the database value of the hashed value. This method is helpful in securing authentication process. We, in this paper, used human computation method to gain click points or Pass Points from the user and to predict hot spots.

## PROPOSED APPROACH

Graphical text CAPTCHA is commonly used for the authentication of humans from bots (Kheshaifaty & Gutub, 2020). Its drawback can be in usability as humans may find difficulty reading them due to high distortion to be secure. This paper proposed the engineering methodology integration of graphical CAPTCHA with encryption standard (AES) 256 bits and SHA 256 hash function to overcome these usability security challenges (Kaur, 2016). This engineering methodology improved the security for the system and user data from unauthorized attempts improving research in (Kahri et al., 2013). Figure 2 shows the proposed system CAPTCHA Hash Encryption framework.

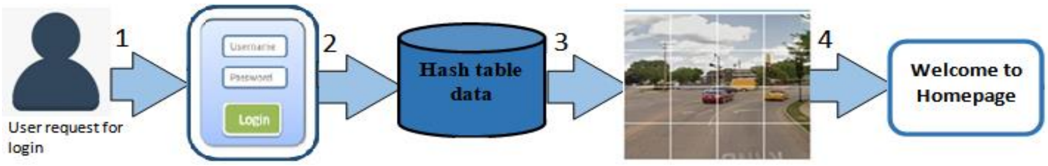


**Figure 2.** Proposed system framework

The research proposed graphical password to prevent active guessing attacks and shoulder surfing attacks as well as bot auto programs and replay attacks, justifying common CAPTCHA technology built on graphical password, known as (CaRP) (Kulkarni & Malwatkar, 2015). CaRP provided reasonable usability and security (Kahri et al., 2013), as our login part is designed to start the system by providing a new image every refresh or new attempt. To access the system the user has to click on the same point based on visual CAPTCHA creation of CaRP images. Figure 3 show cases a sample of the CaRP images introduced in our system.

**Figure 3.** Example of CaRP images used in our proposed system

The second part building our proposed engineering system adopted the Standard AES (256) bits encryption, as a block cipher compulsory technique for maintaining security (Alsaidi et al., 2018). The original data is scrambled by mathematical calculations. The encrypted data is to be shown in the original form only with the help of the key (Shimazaki et al., 2016). AES is working with a symmetric key cipher. For encryption and decryption purposes the same key is used. This symmetrical algorithm needs less computational power and faster to run. AES 256 bits provide security through a complex level of encryption. Figure 4 shows the AES overview mechanism.

The third component of our proposed engineering mechanism consists of hashing. In hashing, the resolution of collision can be resolved by utilizing specific function and hash lookup tables (Shimazaki et al., 2016), as it greatly affects the complete system performance. Figure 5 highlights the mechanism of the hash table.

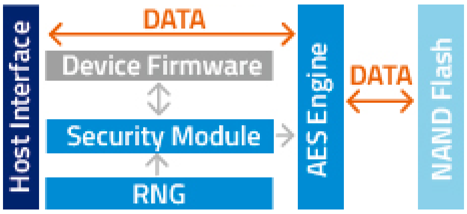


**Figure 4.** Secure mechanism of the AES 256

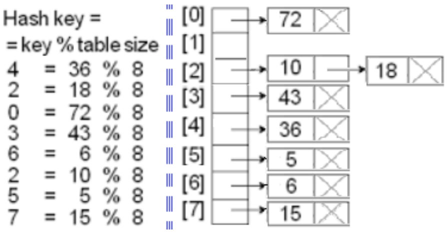


**Figure 5.** Hash table performance

The applications of hash functions are popular to be considered in the hash table structure found appropriate utilizing SHA 256, as secure functions improving SHA-1 (Zhang et al., 2019). Table 2 briefs the SHA specs. Beside SHA 256 security and speed strength, it is found compatible with encryption function AES 256 bits, making our selection appropriately tuned. The implementation of the system is run on JAVA platform as generated by the multiple blocks of 512 each bit. The cycles of our SHA 256 take the input expanded in words of 32 each bit similar to work of (Kahri et al., 2013). Figure 6 shows a type of iteration.

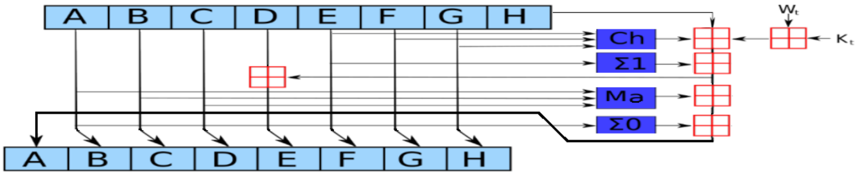


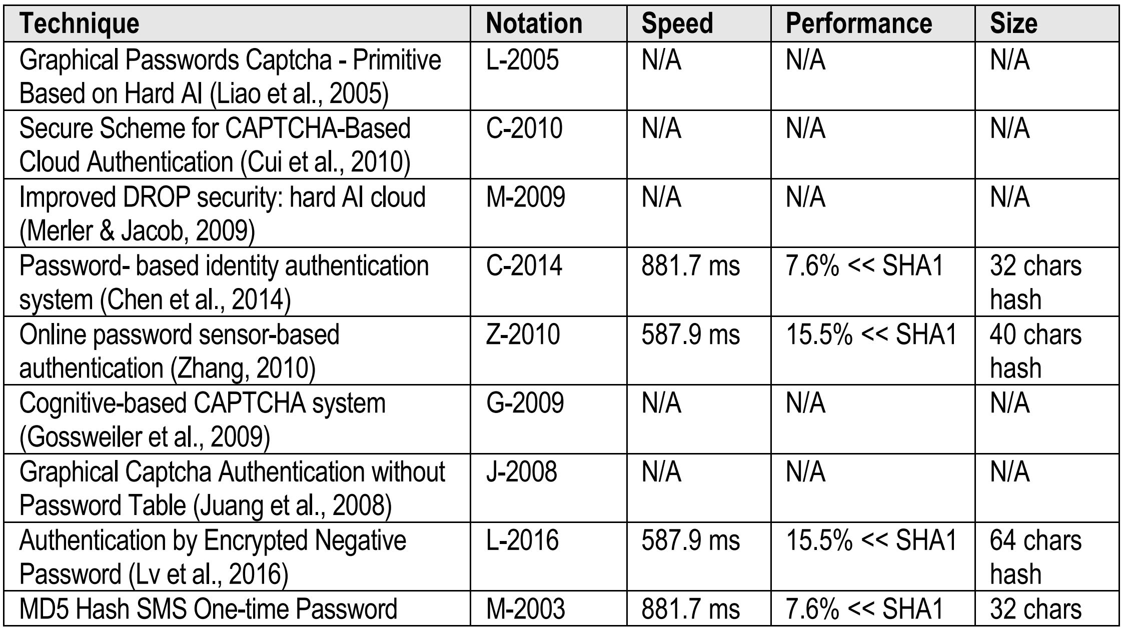
**Figure 6.** An iteration of SHA-256 hash function

**Table 2.** Hash function Specification

| SHA 256 Hash Function | | | | |
|---|---|---|---|---|
| **Function** | **Digest size** | **Collision** | **First preimage** | **Throughput (MiB/second)** |
| SHA256 | 25 | $2^{128}$ | $2^{256}$ | 275 |

The proposed engineering scheme consists of 3 layers of graphical CAPTCHA, AES 256 bits along with SHA 256 hash function, as secure practical mechanism for online website services similar in objective to the work in (Samkari & Gutub, 2019). If the bots programs breaches the security of the any single layer, then it would be complex to break the security of the other 2 layers. Table 3 shows how the proposed system has attractive performance in terms of security and usability defending security risks of password guessing, keylogging, phishing, and unauthorized user access to the system, linking the references with proper study used notations.

**Table 3.** Hash running assessment of proposed vs. other relative techniques



| Technique | Notation | Speed | Performance | Size |
|---|---|---|---|---|
| Graphical Passwords Captcha - Primitive Based on Hard AI (Liao et al., 2005) | L-2005 | N/A | N/A | N/A |
| Secure Scheme for CAPTCHA-Based Cloud Authentication (Cui et al., 2010) | C-2010 | N/A | N/A | N/A |
| Improved DROP security: hard AI cloud (Merler & Jacob, 2009) | M-2009 | N/A | N/A | N/A |
| Password- based identity authentication system (Chen et al., 2014) | C-2014 | 881.7 ms | 7.6% << SHA1 | 32 chars hash |
| Online password sensor-based authentication (Zhang, 2010) | Z-2010 | 587.9 ms | 15.5% << SHA1 | 40 chars hash |
| Cognitive-based CAPTCHA system (Gossweiler et al., 2009) | G-2009 | N/A | N/A | N/A |
| Graphical Captcha Authentication without Password Table (Juang et al., 2008) | J-2008 | N/A | N/A | N/A |
| Authentication by Encrypted Negative Password (Lv et al., 2016) | L-2016 | 587.9 ms | 15.5% << SHA1 | 64 chars hash |
| MD5 Hash SMS One-time Password | M-2003 | 881.7 ms | 7.6% << SHA1 | 32 chars |

| | | | | |
|---|---|---|---|---|
| (McLoone & McCanny, 2003) | | | | hash |
| Securing passwordswith CAPTCHA hash over web (Das et al., 2004) | D-2004 | 881.7 ms | 7.6% << SHA1 | 32 chars hash |
| Improved Security Captcha Hash Encrypted [our proposal] | Proposed | **587.9 ms** | **Faster than others** | **40 char s hash** |

Analyzing our method shows preference among others for preventing hacker's database attack from retrieving unauthorized details. Our approach password database solved the common password table clean for reading that aren't using encryption techniques (Das et al., 2007) as well as our usage of CAPTCHA's verification combined for protection against brute force (Ali & Karim, 2014), network folding attacks and DDoS problems (Saini & Anju, 2013). Other systems used crypto accessing algorithms without CAPTCHA verification, which is a weakness solved. We adopted sound CAPTCHA alphabets to provide opportunity to confirm text writing, that should be typed as CAPTCHA verification text, as CAPTCHA can be requested to be refreshed if completely unclear. Our system can be further used by PHP developers for authentication of privacy login passwords adopting encrypted keys (Ahn et al., 2003). The security testing of the system is remarked through the input login information on online web.

Figure 7, shows our proposed methodology graphical CAPTCHA to illustrate this usability feature. This contradiction between distortion and robotic guessing made our proposed methodology have less distorted CAPTCHA images, but protected combining cryptography and hashing (Alotaibi et al., 2019) different than HSV colour space image security (Hassan & Gutub, 2021). Table 4 shows our list of images with user selection speed for proper CAPTCHA images.

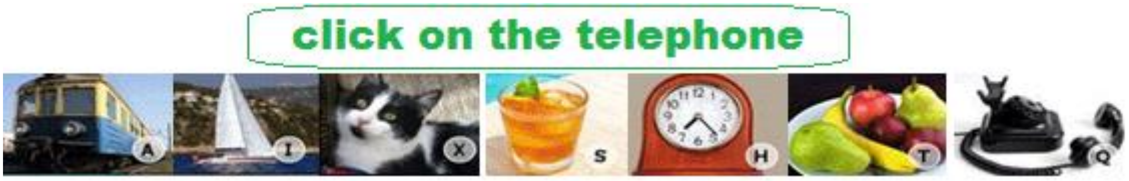


**Figure 7.** Example of proposed methodology CAPTCHA to illustrate usability feature

The proposed strategy implements a comprehensive encryption technique of AES cryptography beside Hashing, which gives a more effective edge to the authentication process. Table 4 shows how all techniques are evaluated for protection, integration and complexity, as marked between low level valued 0, moderate as 1, standard as 2 and our high level as 3.

**Table 4.** Time consumption and complexity table vs security

| Notation | Technique | Delay | Integration complexity | Attack Prevention |
|---|---|---|---|---|
| L-2005 | Graphical Passwords Captcha - Primitive Based on Hard AI | Low | 0 | Relay attack<br>Online guessing attack |
| C-2010 | Secure Scheme for CAPTCHA-Based Cloud Authentication | Delay | 1 | Phishing attack<br>Dictionary attack<br>Guessing password attack |
| M-2009 | Improved DROP security: hard AI cloud | Low | 0 | Password guessing attack |
| C-2014 | Password- based identity authentication system | Modera te | 2 | Dictionary attack |
| Z-2010 | Online password sensor-based authentication | low | 2 | Offline dictionary attack |
| G-2009 | Cognitive-based CAPTCHA system | High | 0 | Dictionary attack |
| J-2008 | Graphical Captcha Authentication without Password Table | Moderate | 0 | DOS attack<br>Impersonating attack |
| L-2016 | Authentication by Encrypted Negative<br>Password | Moderate | 1 | lookup table attack rainbow table attack |
| M-2003 | MD5 Hash SMS One-time Password | Low | 1 | Password attack |
| D-2004 | Securing passwords with CAPTCHA hash over web | low | 2 | Brute force attack<br>Dictionary attack |
| Proposed | **Improved Security Captcha Hash Encrypted [our proposal]** | **Very low** | **3** | **Relay, Online guessing attack, Brute force & Dictionary attack DOS& Password attack** |

Our research calculation performed SHA-256 divided into two steps. In steps 1, SHA-256 dose the preprocessing of the data, followed by round computations where the message is expanded according to it. Through padding, the expansion is accomplished adding extra 512 bits. This is briefed in equation (Alsaidi et al., 2019) below for our testing, where "t" represents the number of rounds, as clarified in depth in literature (Zhang et al., 2019).

$$W_t = \sigma_i^{\{256\}}(W_{t-2}) + W_{t-7} + \sigma_0^{\{256\}}(W_{t-15}) + W_{t-16} \qquad (1)$$

Figure 8 shows the whole computational tasks of the SHA-256. Each round of the SHA-256 can create 8 hash values. The characteristics of the hardware XOR components of the system caused representing the computation round of the SHA-256 algorithm affecting the performance of our engineering system as determined in two categories, Login time and Rate of successful logins, as discussed next.

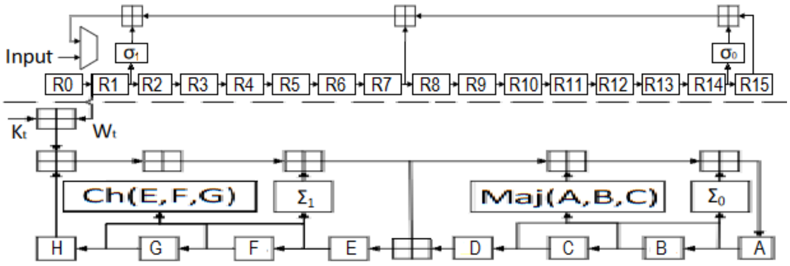


**Figure 8.** SHA-256 Computational scheme

Login time is analyzed by the total time needed by the user to login to the system. As this login time gets smaller as we ensure fast login. Accordingly, SHA-256 algorithm is chosen, as found to be fast in the hashing table by creating keys as used in (Bindu, 2015). On the other hand, the rate of successful login specifies the attempts made by the user to login to the system. This part shows the usability effect in the proposed system to help making the attempts easily accessible. Table 5 shows how relatively specific the performance of SHA-256 is.

**Table 5.** Performance of SHA-256

| Design: SHA-256 | Freq (MHz) | Delay (Cycles) | TP (Mbps) | Area (Slices) | Cost (TP/Area) |
|---|---|---|---|---|---|
| **Basic** | 133.06 | 68 | 1009 | 1373 (12%) | 0.735 |
| **2x-unrolled** | 73.975 | 38 | 996.7 | 2032 (18%) | 0.491 |
| **4x-unrolled** | 40.833 | 23 | 908.9 | 2898 (26%) | 0.314 |

## COMPARATIVE ANALYSIS

The comparison is performed mainly to test the security insurance measures. Hence through deep studies of the previous work loopholes have been analyzed and the proposed approach has reached to present our 3-layers security architecture. Table 6 summaries the contributions, comparison of the advantages and disadvantages of the techniques, including our work

**Table 6.** Systems overall comparisons based on contribution, advantages and disadvantages

| Technique | Contribution | Advantages | Disadvantages |
|---|---|---|---|
| V-2016 | Audio captcha words | Visual impair users | Audio noise and vocabulary |
| A-2014 | Puzzle captcha | Authentication security | Delay in solving puzzle captcha |
| C-2010 | Dynamic CAPTCHA | Defend bots attack | Weak password against phishing |
| K-2016 | Math CAPTCHA | Resists visual attacks | Complex delay login details |

| | | | |
|---|---|---|---|
| L-2016 | Chinese CNN | Recognition accuracy | Low security |
| Z-2017 | Vertical projection | Recognition accuracy | Low reliability |
| A-2003 | Extended captcha | Secure cost-effective | High Risk of DOS attack |
| T-2014 | Key exchange | Provide secure connection | Time delay and complexity |
| C-2014 | Improved smart-card-based password authentication | Achieves mutual authentication | Complex delay login details |
| L-2005 | Security enhancement for dynamic ID-based remote user authentication | No computational cost to improvements | Low reliability |
| J-2008 | User authentication using smart card | Very low cost | Time delay and complexity |
| D-2007 | ID-based remote user authentication | No need for password<br>User can change and choose own password | Does not achieve mutual authentication and the secret key in the login phase |
| M-2003 | New key scheduling method | Application to other encryption algorithms | Complex delay login details |
| M-2009 | Vidoop CAPTCHA that relies on images | Avoid text-input | Recognition accuracy low/low reliability |
| G-2009 | Identifying an image's upright position | Avoids text-input | Low reliability |
| Z-2019 | Zhang's CAPTCHA via intelligent communication with RIA | Two line of defense | Time delay and complexity |
| Proposed | CAPTCHA based encrypted hash | Strong security & practical usability | Improve Hash function efficiency |

Based on Table 6, Vaithyasubramanian (2016) research is only using audio-based CAPTCHA, which is beneficial to users who are visually affected, but may be not very convenient to all. As an overview, Table 7 below summarizes the comparison of promising techniques on basis of the essential authentication layers' availability and practicality.

**Table 7.** Authentication layers' availability and practicality evaluation

| Notation | Technique | CAPTCHA | Hashing | Encryption | Usability |
|---|---|---|---|---|---|
| A-2014 | visual CAPTCHAs and breaking of weak audio CAPTCHAs (Ali & Karim, 2014) | ✓ | ✘ | ✘ | ✓ |
| C-2010 | CAPTCHA System Based on Puzzle (Cui et al., 2010) | ✓ | ✘ | ✘ | ✘ |
| K-2016 | A non-OCR approach (Kaur, 2016) | ✓ | ✘ | ✓ | ✘ |
| A-2017 | Modification based CAPTCHA (Althumaly & El-Alfy, 2017) | ✓ | ✘ | ✓ | ✘ |
| Proposed | Proposed Methodology | ✓ | ✓ | ✓ | ✓ |

Table 7 comparison ensures that our engineering methodology can be applicable to enjoy various characteristics. We involve proper labeling for CAPTCHA images to be clear enough for the user to select images from the grid benefitting from all other schemes.

## CONCLUSION

To ensure secure access to sensitive information is one fundamental challenge in today's e-platforms. Therefore, many techniques were proposed had some issues regarding security such as hacks that breach security and further modify sensitive information. This paper introduces an engineering methodology to protect the secure access to systems in convenient manner. We present combining graphical text-captcha, encryption, and hash function, building highest secure practical system. The testing of security shows resistance to protect against intelligent computer AI coding addressing bots cracking of password. The work involves graphical text-captcha for the user to select exact images from grids. The work tested graphical captcha to provide security against human guessing attacks as well as other common breaches. Future work suggested trying different CAPTCHA schemes, such as audio or video-based captcha, with more advanced encryption techniques. Further advanced Hash functions such as SHA3, can be tested aiming higher security, as believed coming e-platforms needing to mitigate improved hacker attacks, i.e. that need further unconventional anti-hacking refinement.

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