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3D CAPTCHA: A NEW GENERATION OF CAPTCHA

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ทุกวันนี้, อินเตอร์เน็ต ได้เข้ามาเป็นส่วนหนึ่งในชีวิตประจำวันของพวกเราทกคน บริการหลายอย่าง, รวมถึง อีเมล์, เครื่องมือสืบค้น และกระดานข่าวบนอินเตอร์เน็ต เปิดให้ใช้บริการโดยไม่คิดค่าใช้จ่าย และสิ่งนี้ นำไปสู่การเปิดช่วงโหว่ โดยไม่ได้ตั้งใจ โปรแกรมที่ทำงานโดยอัตโนมัติทั้งหลาย หรือเรียกสั้นๆ ว่า บ๊อตนั้นถูกพัฒนาขึ้นมาเพื่อใช้บริการเหล่านี้ในทางที่ผิด ดังนั้นบรรดาเวปไซต์ต่างๆ จึงใช้ระบบตรวจสอบความเป็นมนุษย์ที่เรียกว่า แคปต์ชา มาใช้เพื่อต่อต้านการใช้บริการในทางที่ผิดนี้

โชคไม่ดีที่บรรดาระบบแคปต์ชา ทั้งหลายนั้นถูกทำลายโดยบ็อตได้แล้ว และบางระบบนั้นอ่านได้ยากโดยมนุษย์ด้วยกันเอง ในวิทยานิพนธ์นี้ ได้นำเสนอระบบแคปต์ชา แบบใหม่ที่เรียกว่า แคปต์ชา 3 มิติ ขึ้นมาเพื่อทำให้สามารถต่อต้านการโจมตีจากบ็อตได้ดีขึ้น ระบบนี้อยู่บนสมมุติฐานที่ว่า มนุษย์นั้นสามารถวิเคราะห์ภาพตัวอักษร 3 มิติได้ดีกว่าบ็อตมาก ยิ่งกว่านั้น ในวิทยานิพนธ์ฉบับนี้ยังเสนอ แคปต์ชา 3 มิติ ในรูปแบบภาพเคลื่อนไหว เพื่อเพิ่มการป้องกันจากบ็อตให้ดีขึ้นไปอีก โดยในระบบนี้จะมีการใช้ภาพมากกว่าหนึ่งภาพมาใช้ ซึ่งแตกต่างจากระบบแคปต์ชาอื่นๆ ทีใช้ภาพเพียงภาพเดียว

ภาควิชา คณิตศาสตร์ ลายมือชื่อนิสิต......มนตรี อิ่มสมัย......
สาขาวิชา วิทยาการคอมพิวเตอร์และสารสนเทศ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก.......
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Nowadays, the internet is now becoming a part of our everyday lives. Many services, including Email, search engine, and web board on internet, are provided with free of charge and unintentionally turns them into vulnerability services. Many software robots or, in short term, bots are developed with purpose to use such services illegally and automatically. Thus, web sites employ human authentication mechanism called Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA) to counter this attack.

Unfortunately, many CAPTCHA have been already broken by bots and some CAPTCHA are difficult to read by human. In this thesis, a new CAPTCHA method called 3D CAPTCHA is proposed to provide an enhanced protection from bots. This method based on the assumption that human can recognize 3D character image better than automated program bots. Moreover, this thesis also introduces the 3D - animation CAPTCHA method to increase protection from bots. This method includes multiple image frames instead of using a single frame found in general CAPTCHA.

Department : Mathematics

Field of Study : Computer Science and Information

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Student's Signature ....

Advisor's Signature ....

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May I dedicate this work to all the people as I mentioned above. Without them, this work will never be done. Throughout this thesis, I had encountered many problems, but they were trivial, compared to all the supports given by these people. The encouragement from them was so great and those impressions will always be remembered.

CONTENTS

CHAPTER PAGE

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Turing Test [1] is a test for determining whether or not machine intelligence can converse like a human. This test has three participants – two subjects and judge. One of the subjects is a person and the other is a computer. Both subjects are hidden from the view of the judge. They communicate with the judge via text-only channels. The role of the judge is to determine which text channel corresponds to the human and which corresponds to the computer. If the judge cannot determine this, then the computer passes the test.

Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA) is similar to Turing Test but the judge is a computer [2]. The basic idea is that the distorted image of a sequence of letters and numbers is shown to a user and asked to type that sequence. The user will have no problem to recognize all alphabets letters and numbers, but the computer programs or bots cannot recognize them.

The CAPTCHA is usually a simple visual test or puzzle that a human can complete without much difficulty, but an automated program cannot understand. The test usually consists of letters, numbers or their combination with overlapping and intersection. The CAPTCHA images may be distorted in some way or shown against an intricate background to keep them from being easily read by Optical Character Recognition (OCR) software.

The CAPTCHA is used to keep bots and other automated programs from signing up for offers, collecting or signing up for email address, violating privacy, trying to crack passwords, or sending out spam to unsuspecting email recipients.

The CAPTCHA methods can be divided into two groups: OCR-based and non-OCR-based methods as follows.

1- OCR-based method: The distorted image of a word is shown to the user. After that the user is asked to type that word. This method is based on the weakness of the OCR software because this software has difficulty reading text from distorted image. Examples of these methods are using by Google, Hotmail, and Yahoo method.

2- Non-OCR-based method: Instead of show the distorted image of a word and ask user to type it. This method based on the features of multimedia systems such as pictures, sound, and videos. Examples of these methods are Implicit CAPTCHA [3], Collage CAPTCHA [4], and Text-to-Speech [5].

The CAPTCHA methods are being introduced into the Internet at an increasing rate. Research in the area of the CAPTCHA has followed several avenues. Early work by Yahoo and Camegie Mellon University (CMU) [6] picks English words at random and transforms them into an image after severe deformation and image occlusion with some overlapping. A. L. Coates, H. S. Baird, and R. Fateman developed method call PessimalPrint [7]. This method contains only 70 common English words which are between 5 to 8 characters. Additional work by M. Chew and H. S. Baird [8] deals with the design of a reading-based CAPTCHA that uses random masking to degrade images of non-English pronounceable characters strings.

Several researchers addressed the problem of security weaknesses in the CAPTCHA. G. Mori and J. Malik [9] have broken the Gimpy and the EZ-Gimpy with sophisticated object-recognition algorithms. J. Yan and A.S. El Ahmad [10] combine methods to segment noisy Microsoft CAPTCHA.

In this thesis, a new CAPTCHA method called 3D CAPTCHA has been introduced. Instead of using a sequence distorted 2D characters like other old methods, this method uses a sequence of 3D characters together with rotation, translation, and scaling in 3D dimension. The advantage of this method is that human can recognize a 3D character image better than automated program bots. To increase the protection from bots, this thesis also introduces 3D animation CAPTCHA that uses multiple image frames to generate the CAPTCHA.

The 3D CAPTCHA method is based on an OCR-based method. The advantage of this method is that it is similar to those of the other many well known web sites and services where users type some keywords or characters into an input box. Thus it is easy to learn and use by any user.

1.1 Objectives

1. To analyze the existing CAPTCHA methods.
2. To design the CAPTCHA that human user can read easily.
3. To develop the 3D CAPTCHA method.
4. To develop the 3D animation CAPTCHA method.
5. To review the security strength of the proposed method.

1.2 Scope of the Work

The research work will focus to the following:

1. Ten existing popular CAPTCHA methods are considered in this study as follows: Steam Forums, Google, Hotmail, Friendster, eBay, Yahoo, Rediffmail, pc1news, Jeans SMS, PHP-CAPTCHA-Class
2. Proposed 3D CAPTCHA is designed based on ten designing factors: Rotation, Overlapping, Obstacle such as straight line, Distributed Noise, Character Color, Background Color, Scaling, Font, Special Character, Background Texture
3. The new CAPTCHA method is based on English alphabet and digit.

4. The new CAPTCHA method is design to both static and animated schemes.

1.3 Problem Formulation

1. How to build a strong CAPTCHA method.
2. What is a design factors to consider for develop the proposed method.
3. How to get a survey from users.
4. How to evaluate the security strength of the proposed method.

1.4 Scheduling

Table I. Time Table.

No	Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Studying the related works																		
2	Define problem of the study																		
3	Design the methodology to solve the defined problem																		
4	Get survey from web site																		
5	Testing experiment																		
6	Evaluation experiment																		
7	Conclude the results of study																		
8	Write thesis																		

1.5 Expected Outcomes

The expected outcomes will be as follows:

1. A collection of the security problems of current CAPTCHA methods.
2. A prototype of new CAPTCHA method.
3. An implementation of the 3D CAPTCHA method.
4. An implementation of the 3D animation CAPTCHA method.

CHAPTER II

THEORETICAL FOUNDATION

DirectX is a rich multimedia API that allows developers to write high-performance applications using a standardized set of interfaces. The first release of DirectX coincided with Windows 95, and was called the "Games SDK." Since more than eight version of the API are based on C and C++, this causes difficulty of functionality access for the developers who have no skill on such programming languages.

2.1 The Managed DirectX

The first public Managed DirectX is released on December 20, 2002 in the release of DirectX 9. However, the project had been developed for quite a long time. The Managed DirectX provides the developers to use .NET language such as Visual Basic.NET and C#.NET.

From the beginning, Managed DirectX was designed to be just as powerful as the "core" API, with little overhead. In the past, Visual Basic users of DirectX lacked the ability to develop applications of similar quality when compared to the development on the core DirectX API. Some of this was caused by the Visual Basic runtime itself, while some was caused by the overhead of the wrapper DLLs.

After the release of DirectX 8, it was apparent that the API was not very easy to use. The samples were hard to follow and the code did not look like normal Visual Basic applications. Most Visual Basic developers found that the API is too complicate to use, they had no reason to switch since there was no benefit for them. Therefore, the concept for Managed DirectX was born.

2.2 DirectX Namespaces

The Managed DirectX API has a relatively obvious set of namespaces, breaking down the functionality into the various "core" components housed in DirectX. There is also the generic "Microsoft.DirectX" namespace that houses the common functionality. The full list of namespaces included in Managed DirectX is listed in Table II.

Table II. Managed DirectX Namespaces

Namespace	Description
Microsoft.DirectX	Parent namespace, holds all common code.
Microsoft.DirectX.Direct3D	Direct3D graphics API, as well as the D3DX helper library.
Microsoft.DirectX.DirectDraw	DirectDraw graphics API.
Microsoft.DirectX.DirectPlay	DirectPlay networking API.
Microsoft.DirectX.DirectSound	DirectSound audio API.
Microsoft.DirectX.DirectInput	DirectInput user input API.
Microsoft.DirectX.AudioVideoPlayback	Simple audio and video playback API.
Microsoft.DirectX.Diagnostics	Simple diagnostics API.
Microsoft.DirectX.Security	Underlying structure for DirectX code access security.
Microsoft.DirectX.Security.Permissions	Permission classes for DirectX code access security.

2.3 Direct3D

One of the most popular aspects of "rich multimedia" applications would be the addition of 3D graphics. With the processing power of today's modern GPU (graphics processing unit), realistic scenes can be rendered in real time. Managed Direct3D allows developers an easy and fast way to get complex or simple graphics and animations on the screen.

2.4 Coordinate Systems

In most Cartesian 3D coordinate systems, positive x coordinates move toward the right, while positive y coordinates move up. The only other coordinate left is z. Direct3D uses a left-handed coordinate system. In a left-handed coordinate system, positive z moves away from you, while in a right-handed coordinate system, positive z moves toward you. You can easily remember which coordinate system is which by taking either hand and having your fingers point toward positive x. Then twist and curl your fingers so they are now pointing to positive y. The direction your thumb is pointing is positive z as shown in Fig. 1.

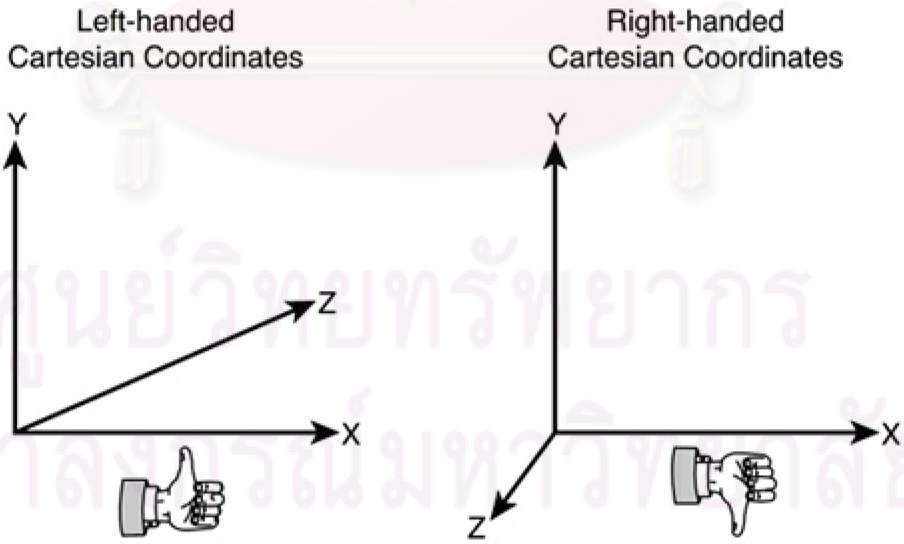


Figure 1. 3D coordinate systems.

2.5 Direct3D System Integration

This figure shows the relationships between a Window application, Direct3D,GDI, and the hardware as shown in Fig. 2.

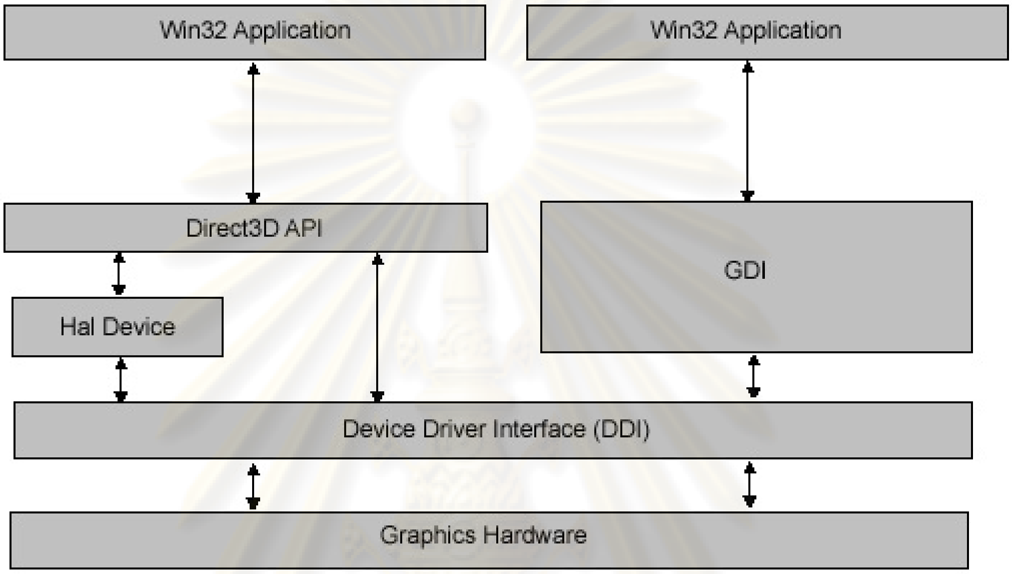


Figure 2. Direct3D System Integration.

Direct3D exposes a device-independent interface to an application. Direct3D applications can exist alongside GDI applications, and both have access to the computer's graphics hardware through the device driver for the graphics card. Unlike GDI, Direct3D can take advantage of hardware features by creating a hal device.

A hal device provides hardware acceleration to graphics pipeline functions, based upon the feature set supported by the graphics card. Direct3D methods are provided to retrieve device display capabilities at run time. If a capability is not provided by the hardware, the hal does not report it as a hardware capability.

2.6 Light

The light type property defines which type of light source you're using. There are three types of lights in Direct3D - point lights, spotlights, and directional lights. Each type illuminates objects in a scene differently, with varying levels of computational overhead.

2.6.1 Point Light

Point lights have color and position within a scene, but no single direction. They give off light equally in all directions, as shown in the following illustration in Fig. 3.

2.6.2 Directional Light

Directional lights have only color and direction, not position. They emit parallel light. This means that all light generated by directional lights travels through a scene in the same direction. Imagine a directional light as a light source at near infinite distance, such as the sun. Directional lights are not affected by attenuation or range, so the direction and color you specify are the only factors considered when Direct3D calculates vertex colors. Because of the small number of illumination factors, these are the least computationally intensive lights to use.

2.6.3 Spotlight

Spotlights have color, position, and direction in which they emit light. Light emitted from a spotlight is made up of a bright inner cone and a larger outer cone, with the light intensity diminishing between the two, as shown in the following illustration.

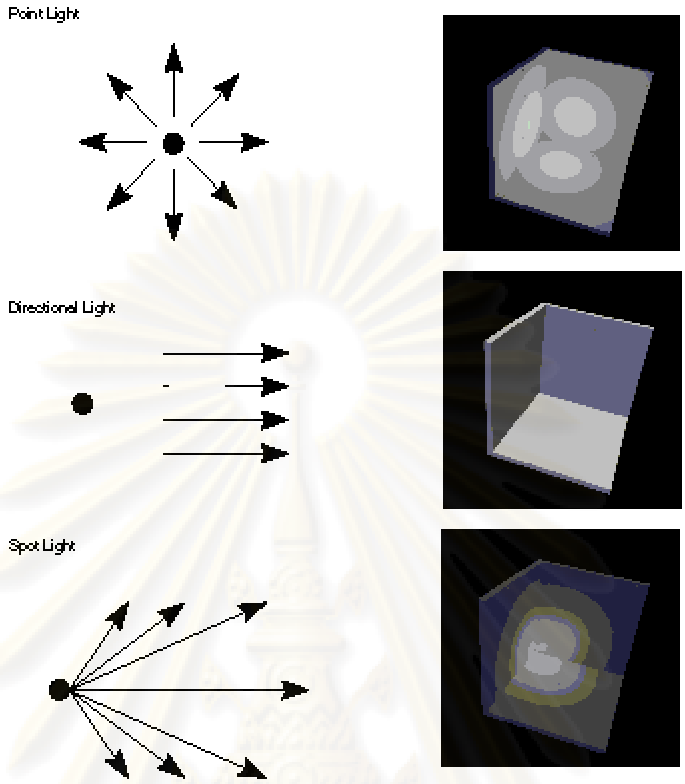


Figure 3. Light Types.

2.7 Transforms

The part of Direct3D that pushes geometry through the fixed function geometry pipeline is the transform engine. It locates the model and viewer in the world, projects vertices for display on the screen, and clips vertices to the viewport. The transform engine also performs lighting computations to determine diffuse and specular components at each vertex.

Transforms are used to convert object geometry from one coordinate space to another. Direct3D uses matrices to perform 3D transforms. This section explains how matrices create 3D transforms, describes some common uses for transforms, and details how you can combine matrices to produce a single matrix that encompasses multiple transforms. There are three types of transforms in Direct3D - rotate, scale, and translate transforms.

2.7.1 Rotate

The transforms described here are for left-handed coordinate systems, and so may be different from transform matrices that you have seen elsewhere. The following matrix rotates the point (x, y, z) around the x-axis, producing a new point (x', y', z') as shown in Fig. 4.

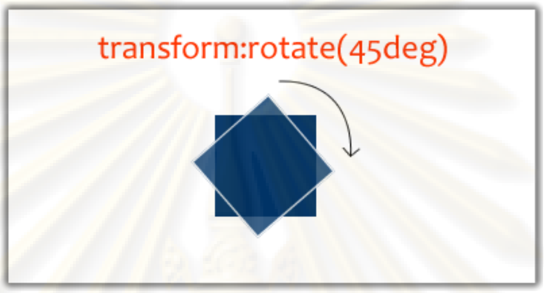


Figure 4. Rotate Transform.

2.7.2 Scale

The following transform scales the point (x, y, z) by arbitrary values in the x-, y-, and z-directions to a new point (x', y', z') as shown in Fig. 5.

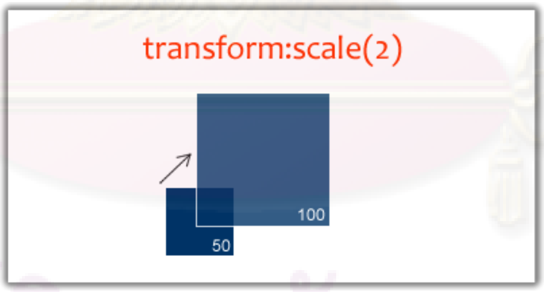


Figure 5. Scale Transform.

2.7.3 Translate

The following transform translates the point (x, y, z) to a new point (x', y', z').

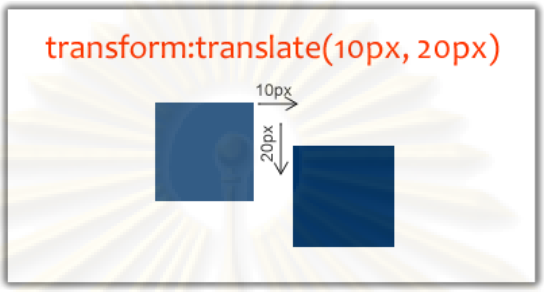


Figure 6. Translate Transform.

2.8 Related Works

The following are ten examples of the CAPTCHA methods currently being used on the Internet today:

2.8.1 Steam Users' Forums

Steam Users' Forums [11] use the CAPTCHA when anonymous users want to perform a search. This CAPTCHA method is consists of 6 characters including letter and number. The color of character is very dim and background is noisy. A related example is depicted in Fig. 7.

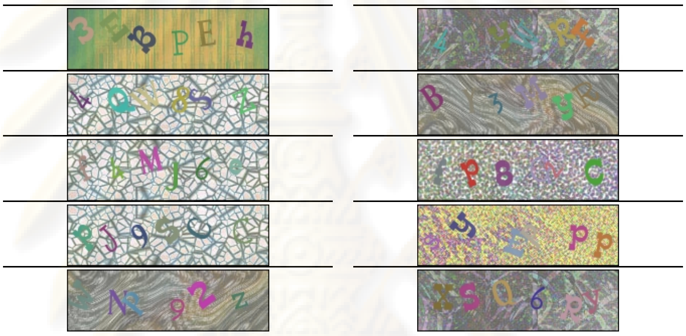


Figure 7. The CAPTCHA used by Steam.

2.8.2 Google

Google [12] uses the CAPTCHA in many places. It is shown when URLs are added to Google and a new Gmail account is signed up. It is obvious that Google does not add background to the image. The sequence is shown in a pure white background. The characters are in single color such as green, red, and blue. It can also be seen that a Google CAPTCHA uses many fonts but all the characters in a sequence will be of the same font. The examples are shown in Fig. 8.

Figure 8. The CAPTCHA used by Google.

2.8.3 Hotmail

The CAPTCHA method that used by Microsoft [13] is typically present users with a sequence of characters that can be recognized by humans, but not by OCR software. Microsoft's system is used for services including Hotmail, MSN and Windows Live as shown in Fig. 9.

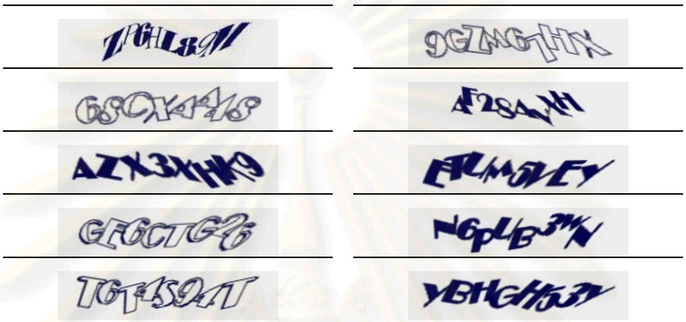


Figure 9. The CAPTCHA used by Hotmail.

2.8.4 Friendster

The CAPTCHA used by Friendster [14] use many fonts in a sequence. The character is colorful and easy to read. It is not overlapping between each other. Some examples are shown in Fig. 10.

Figure 10. The CAPTCHA used by Friendster.

2.8.5 eBay

eBay [15] use the CAPTCHA when a new user want to register for a new account. This method use only number in the sequence and no background is added. Some examples are shown in Fig. 11.

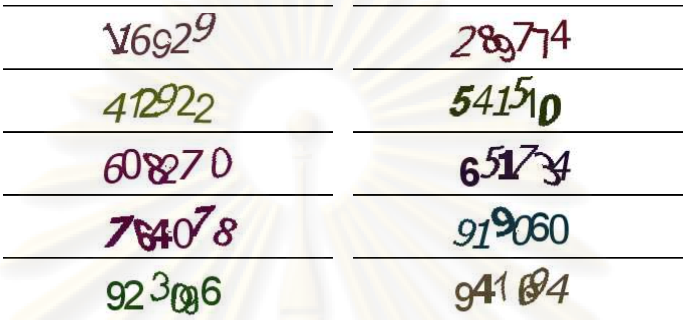


Figure 11. The CAPTCHA used by eBay.

2.8.6 Yahoo

The CAPTCHA used by Yahoo [16] is a black character in white background. The length of the sequence is not fix, it random between 6 – 8 characters. Examples of this method are shown in Fig. 12.

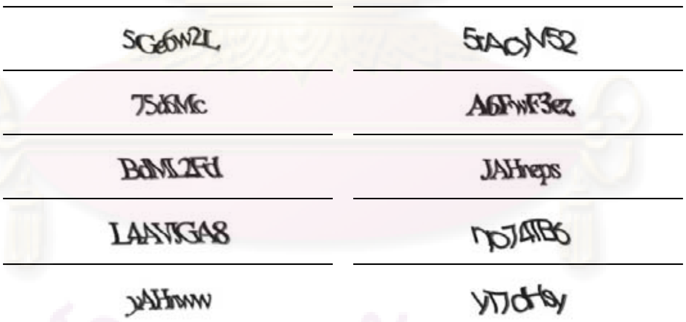


Figure 12. The CAPTCHA used by Yahoo.

2.8.7 Rediffmail

Rediffmail [17] is free e-mail service web site. Some characters are overlapping but difficult to read. Background is very noisy as shows in Fig. 13.

Figure 13. The CAPTCHA used by Rediffmail.

2.8.8 pc1news

The CAPTCHA used by pc1news [18] is easy to read. It uses a constant font. No overlapping between each character. Line noise is easy to remove and segmentation is done very easy. Examples are shown in Fig. 14.

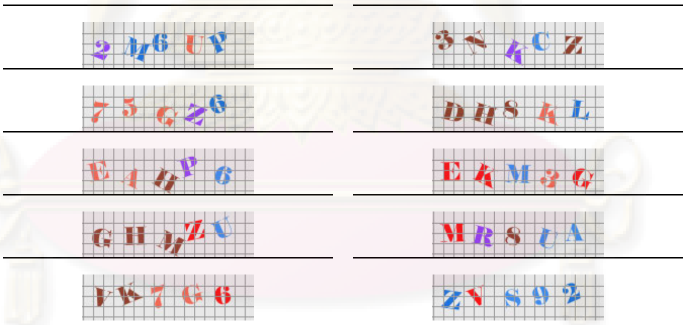


Figure 14. The CAPTCHA used by pc1news.

2.8.9 Jeans

Jeans Mobile Operator [19] uses this CAPTCHA before users perform to send a SMS. This method is not secure. Due to color model separating to characters is very easy in segmentation. Examples of this method are shown is Fig. 15.

Figure 15. The CAPTCHA used by Jeans.

2.8.10 PHP-CAPTCHA-Class

This is a free CAPTCHA class [20] that use in PHP web site. This class will generate a form with a CAPTCHA picture with 5 characters long including letters and numbers. It use various font faces. Background texture can confuse user because it include character-like image. Examples are shown in Fig. 16.

Figure 16. PHP-CAPTCHA-Class.

CHAPTER III

SYSTEM DESIGN

In this thesis, the CAPTCHA design will largely focus on OCR-based CAPTCHA, for the following reasons.

First, OCR-based CAPTCHA have been the most widely used. Many web sites such as Google, Hotmail and Yahoo have their own OCR-based CAPTCHA method.

Second, OCR-based CAPTCHA have many advantages compared to other types of schemes, for example, being intuitive to users world-wide (the user task performed being just character recognition), having few localization issues, and having good potential to provide strong security (e.g. the space a brute force attack has to search can be huge, if properly designed).

Third, it can be recognizable by human users and difficult to read by bots. It uses a same input method similar with the other many well known web sites and services where users type some keywords or characters into an input box. Thus it is easy to learn and use by any user.

3.1 Design Pattern

3.1.1 The Distortion Method

The most intuitive usability concern for an OCR-based CAPTCHA is its readability, which can be largely determined by what distortion methods are used and how much distortion is applied to texts. The distortion methods are list as the following:

Translation: moving characters either up or down, left or right by and in or out.

Rotation: turning characters either in clockwise or counter clockwise direction.

Scaling: stretching or compressing characters in the x-direction, y-direction, and z-direction.

Distortion often creates ambiguous characters, where users cannot be certain what they are. Although some characters have very different shape, after distortion, they become hard to tell apart from each other. Characters that look similar in one typeface can look differently in another typeface. So typeface is another related usability issue.

3.1.2 Character Set

The size of the character set used in a CAPTCHA matters for security. Typically, the larger the character is set, the higher resistance to random guessing attacks each challenge can have. However, a larger character set can also imply a higher number of characters that look similar after distortion, causing confusion.

3.1.3 String Length

The length of the text string used in each challenge also matters for security. If both the character set size and the string length are small, random guessing would have a high chance of passing the CAPTCHA. Typically, the longer the string is used in a challenge, the more secure the result is.

3.1.4 The use of Color

Color is extensively used in user interfaces. When properly used, color can much enhance user interface design. Color can make CAPTCHA challenges interesting. In addition, color schemes might also be expected to work as an additional defense against OCR software which does not do well in segmenting color images.

3.2 Design Aspect

The CAPTCHA usually determines that the usability criteria are applicable to address hit ratio, usability, preference, and time consuming.

Hit Ratio: How accurate can a user pass a CAPTCHA challenge? For example, how many times user has to try in order to pass a test?

Usability: How difficult to use a CAPTCHA? Are users subjectively satisfied CAPTCHA? Would they be willing to use such a scheme?

Preference: How pleasant to use the design?

Time Consuming: How long does it take to pass the test?

3.3 Implementation Process

The implementation process of the CAPTCHA is shown as Fig. 17.

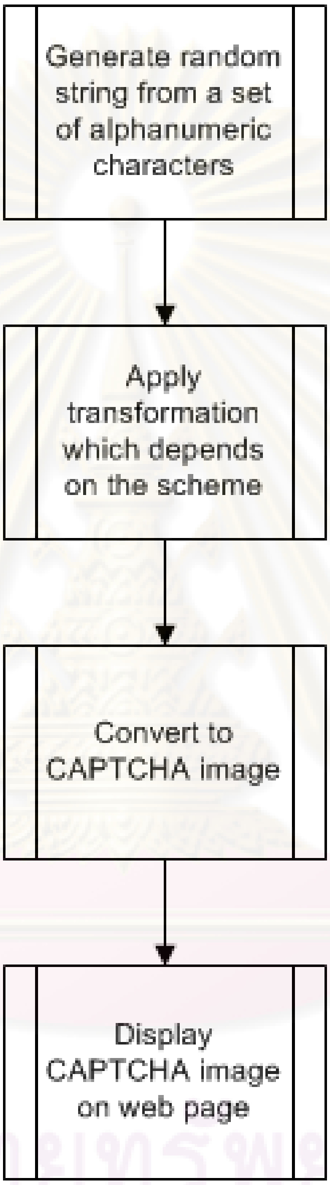


Figure 17 Implementation Process.

CHAPTER IV

3D CAPTCHA

In this thesis, the proposed method has been developed to distinguish human users and computer programs from each other by the same fact that human user can recognize a sequence of 3D characters easily [21] but it makes OCR program a lot of confusing while identifying the characters. There are two major issues involved in building a strong CAPTCHA solution. First, the basis for the puzzle or challenge must be something that is truly difficult for computers to solve. Second, the way puzzles and responses are processed must easy for human users.

The puzzle must be very difficult for computers to solve and relatively easy for humans. Simple character recognition is not one of those problems, despite the fact that users are so used to see it on the sites frequently. On those sites that are successfully using warped text, the real problem preventing scripting is segmentation.

OCR is still not as good as humans to determine where one character ends and the next one begin. The basis for a strong OCR-based CAPTCHA is ensuring that segmentation is hard. In fact, once segmentation is solved, computers are much better at recognizing individual characters than users are. This means that characters should have some overlap and any decoy lines with thickness. Type should also run in the same direction as the strokes that compose the letters.

In our method, the CAPTCHA text consists of the alphanumeric characters which are letters and numbers. The text is composed of six characters, and each of which has its own axis and rotation angle. Each character is rotated in a certain angle ranging from -45 degree to 45 degree by using standard randomization function. In our experiment, the CAPTCHA images are generated by using DirectX, a programming library consisting of many functions to manipulate a 3D picture as well as a function that draws a 3D text. A web site for evaluation is written in ASP.NET (C# language). This web site gets a survey from users about this proposed method.

In 3D space, an object contains three dimensions corresponding to three axes which are x-axis, y-axis, and z-axis. This relates to many 3D-factors. In this thesis, ten proposed factors are selected to adjust a sequence of characters as follows:

- Rotation
- Overlapping
- Obstacle such as straight line
- Distributed Noise
- Character Color
- Background Color
- Scaling
- Font
- Special Character
- Background Texture

These factors are applied to a sequence of alphanumeric characters and can be categorized to 3D CAPTCHA schemes as follows:

4.1 Scheme 1: 3D CAPTCHA with rotation

All characters contain a same color but each has its own rotation angles in three axes. Our method uses a left-handed Cartesian coordinate system. While the values on the x-axis increase from left to right. The values on the y-axis increase from bottom to top and the values on the z-axis increase from back to front. Each character is rotated in an individual angle ranging from -45 degree to 45 degree. The range of rotated angle is limited because some characters seem to be the same if the angle is out of the range. This angle is randomly generated by using standard randomization function. Examples of this CAPTCHA are shown as Fig. 18.

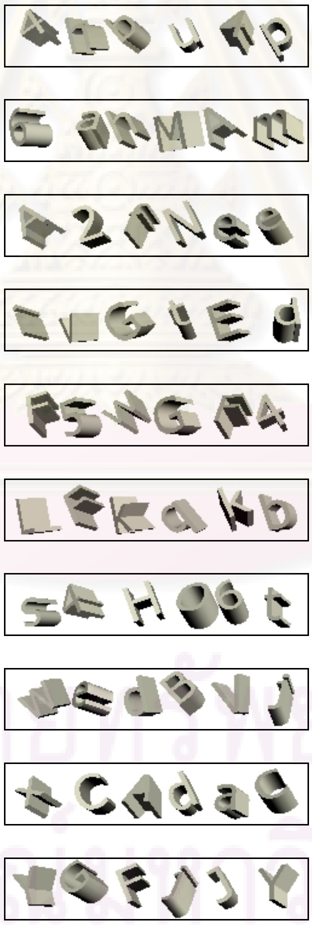


Figure 18. Scheme 1: 3D CAPTCHA with rotation.

4.2 Scheme 2: 3D CAPTCHA with overlapping characters

This factor is similar to the first factor but it has some characters overlapping with adjacent characters. Such characters often cause a segmentation problem. Examples of this CAPTCHA are shown as Fig. 19.

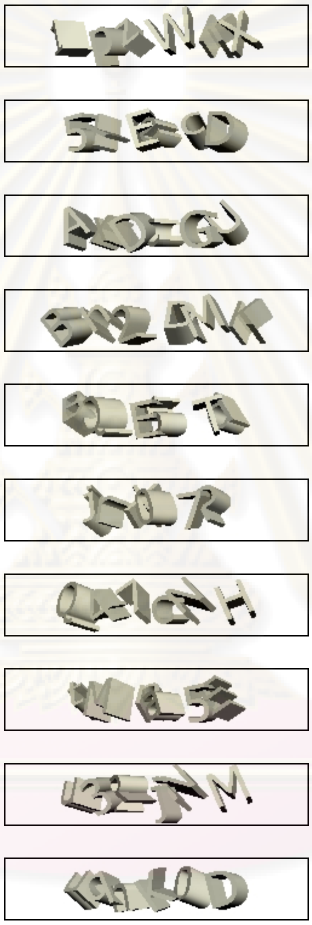


Figure 19. Scheme 2: 3D CAPTCHA with overlapping and rotation.

4.3 Scheme 3: 3D CAPTCHA with rotation and straight line

The straight line is drawn across a sequence of characters. This line is a 3D model and as thick as character. Examples of this CAPTCHA are shown as Fig. 20.

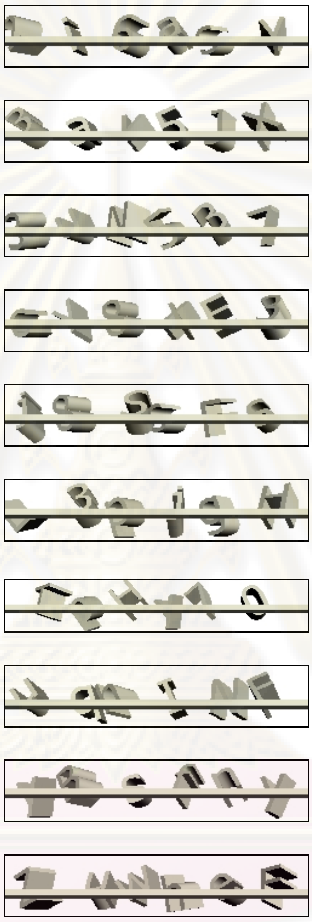


Figure 20. Scheme 3: 3D CAPTCHA with rotation and straight line across a sequence.

4.4 Scheme 4: 3D CAPTCHA with distributed noise of characters

This scheme is done by placing noises into the image pixel. It causes the difficulty level is higher of predicting by OCR because of reduction of image clarity. Often OCR software try to remove noise by color filters however, to prevent this, we set noise color as the same color as the character. The number of pixel noises is randomly generated between 20% and 30% with respect to the size of CAPTCHA. Examples of this CAPTCHA are shown as Fig. 21.

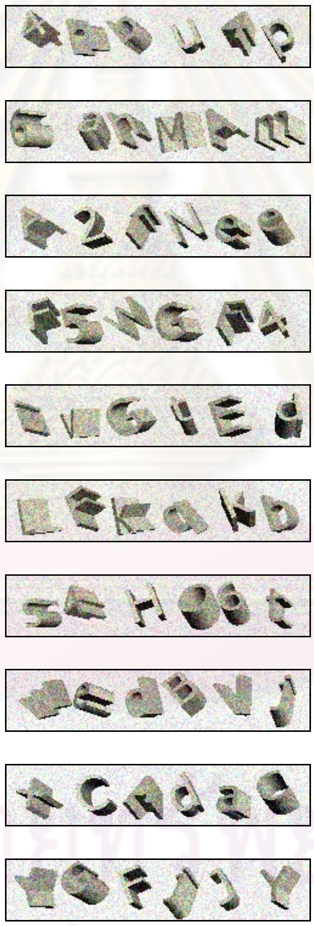


Figure 21. Scheme 4: 3D CAPTCHA with distributed noise and rotation.

4.5 Scheme 5: 3D CAPTCHA with rotation and color background

A background color is used as a main factor for this scheme the first step is adding background color. For the next step the color of text in the CAPTCHA is generated randomly, always within a choice of colors that would contrast sufficiently with the background color, to ensure legibility. Examples of this CAPTCHA are shown as Fig. 22.

Figure 22. Scheme 5: 3D CAPTCHA with rotation and color background.

4.6 Scheme 6: 3D CAPTCHA with rotation and character color variation

Each character contains randomized color to attract user and improve usability. Color is extensively used in user interfaces. When used properly, color can much enhance user interface design. Using color has also been common in OCR-based CAPTCHA methods for the following reasons: color is a strong attention-getting mechanism; color can provide variation to fit different user preferences, and color is appealing and can make the CAPTCHA challenges interesting. In our method, color is randomly generated from red, green and blue color components. Each component represents the intensity of the color in the range of 0 to 255. Examples of this CAPTCHA are shown as Fig. 23.

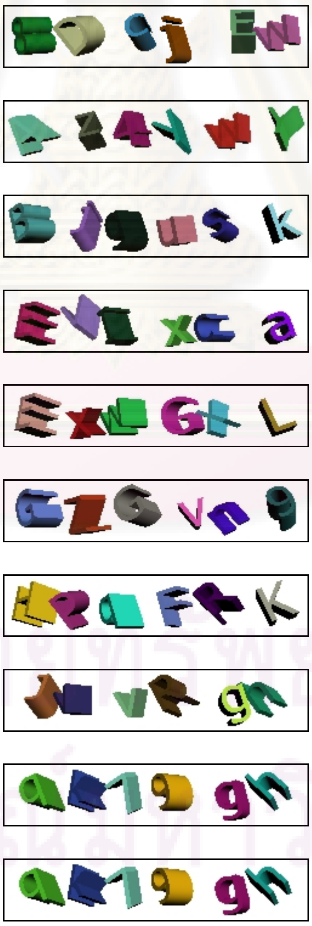


Figure 23. Scheme 6: 3D CAPTCHA with rotation and color variation.

4.7 Scheme 7: 3D CAPTCHA with rotation and character scaling

This method not only uses rotation but also use scaling in each character. Scaling is performing individual in each axis. Scale value is randomly select to perform a half or double in length. Examples of this CAPTCHA are shown as Fig. 24.

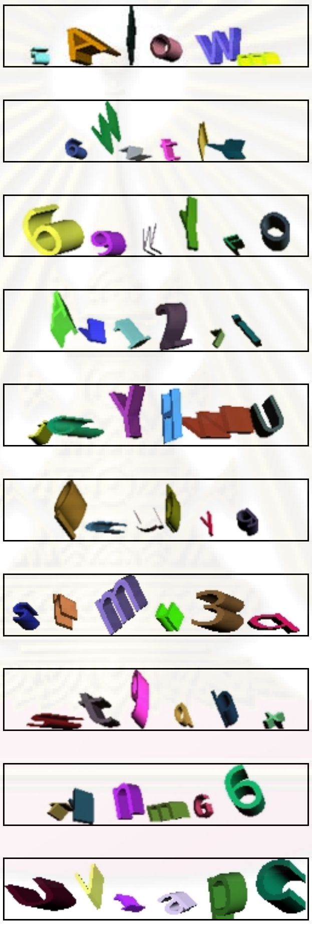


Figure 24. Scheme 7: 3D CAPTCHA with scaling and rotation.

4.8 Scheme 8: 3D CAPTCHA with rotation and font variation

Font selection can also introduce flaws. Font can be broadly divided into serif and sans-serif fonts. Serif contains the small features at the end of individual characters. Some characters of serif font have unique features for certain characters that can make recognition much easier. For this reason, Sans-serif fonts are recommended to be included in our system. Examples of this CAPTCHA are shown as Fig. 25.

Figure 25. Scheme 8: 3D CAPTCHA with two fonts, overlapping and rotation.

4.9 Scheme 9: 3D CAPTCHA with special characters

In order to ensure that the difficulty of OCR is as much as possible, it is important to make sure that there are many possibilities for each character. For instance, if the character set is alphabetic, the recognition task is much simple for software. Use of a full alphanumeric character set is best though typically some characters are eliminated for usability. To increase resistance, it is helpful when the special character is included. Special characters as the following: [!, @, #, $, %, &, *, +, ?] are added to our proposed CAPTCHA. Examples of this CAPTCHA are shown as Fig. 26.

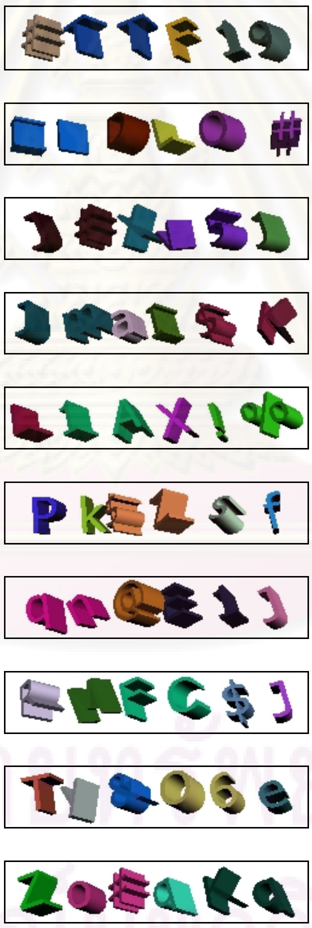


Figure 26. Scheme 9: 3D CAPTCHA with special characters and rotation.

4.10 Scheme 10: 3D CAPTCHA with Background Texture

The basic idea is to use texture composed of random primitives to form the background. This scheme is filling a background layer with a random texture. It is more difficult to defeat since it involves two challenging problems in computer vision, namely, image segmentation and texture analysis. It cleverly makes use of the unique capabilities of human visual systems. Examples of this CAPTCHA are shown as Fig. 27.

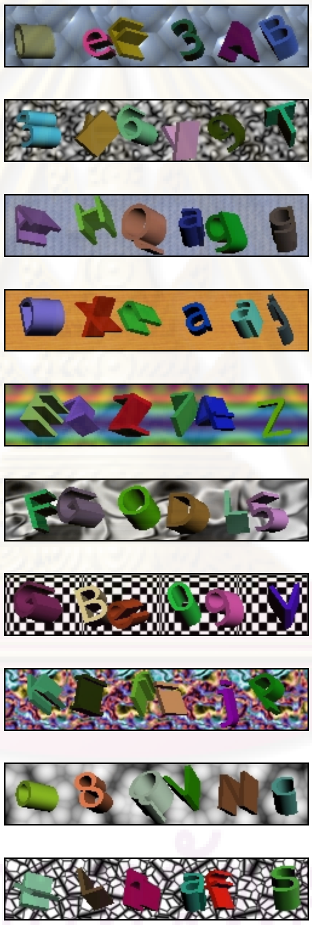


Figure 27. Scheme 10: 3D CAPTCHA with rotation, color variation, and background texture.

CHAPTER V

3D ANIMATED CAPTCHA

Instead of showing a single static image like other CAPTCHA, our proposed method using the multiple images to create the 3D animated CAPTCHA. When bots attempt to decrypt this CAPTCHA, it takes much time to recognize the CAPTCHA. Moreover, a result of recognition is not satisfied because of the difficulty of extracting and recognizing a string of characters from multiple frames of sequential images.

This relates to many 3D-factors. These factors are applied to a sequence of alphanumeric characters and can be categorized to 3D animated CAPTCHA schemes as follows:

5.1 Scheme 1

Scheme 1: 3D animated CAPTCHA with translation, the CAPTCHA sequence is moving from right to left. The value of x-axis in each frame is decreasing by one unit at a time. The average rate of translation is 0.238 characters per second. Examples of this CAPTCHA are shown as Fig. 28.

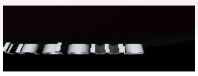
(a)

(b)

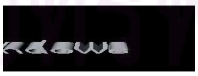
(c)

(d)

(e)



(f)



(g)

(h)

Figure 28. 3D animated CAPTCHA with translation. Some sequential images are shown in order (a) - (h).

5.2 Scheme 2

Scheme 2: 3D animated CAPTCHA with one-by-one appearing character, the CAPTCHA text is appearing one by one at a specific time. Examples of this CAPTCHA are shown as Fig. 29.

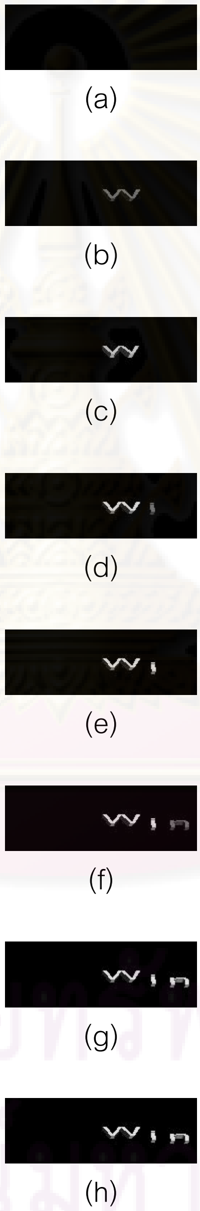


Figure 29. 3D animated CAPTCHA with one-by-one appearing character. Some sequential images are shown in order (a) - (h).

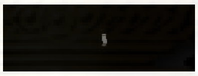
5.3 Scheme 3

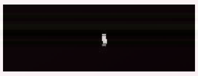
Scheme 3: 3D animated CAPTCHA with fading and appearing at the same position. The CAPTCHA text is appearing one by one at a specific time in the same position. Each character is appearing in pure white color and then fading to black color, so image intensity is gradually changed from 255 to 0. It takes 255 frames between each character appearance. Examples of this CAPTCHA are shown as Fig.30.


(a)


(b)


(c)


(d)


(e)


(f)


(g)


(h)

Figure 30. 3D animated CAPTCHA with fading and appearing at same position. Some sequential images are shown in order (a) - (h).

5.4 Scheme 4

Scheme 4: 3D animated CAPTCHA with spinning, The CAPTCHA sequence is rotated with respect to x-axis. The value of rotation angle is increasing from 0 to 360 degree at a rate of angular velocity of 7 degree per second. Examples of this CAPTCHA are shown as Fig. 31.

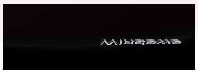
(a)

(b)

(c)

(d)

(e)



(f)

(g)

(h)

Figure 31. 3D animated CAPTCHA with x-axis rotation. Some sequential images are shown in order (a) - (h).

5.5 Scheme 5

Scheme 5: 3D animated CAPTCHA with rotation, the CAPTCHA sequence is rotated along z-axis. The value of rotation angle is increasing from 0 to 360 degree at a rate of angular velocity of 7 degree per second. Examples of this CAPTCHA are shown as Fig. 32.

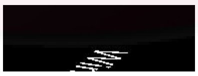
(a)

(b)

(c)

(d)

(e)



(f)

(g)

(h)

Figure 32. 3D animated CAPTCHA with z-axis rotation. Some sequential images are shown in order (a) - (h).

CHAPTER VI

EXPERIMENTAL AND EVALUATION

6.1 3D CAPTCHA

An implementation of this proposed method is available at http://aspspider.info/huskar. A screenshot of the evaluation web site is shown as Fig. 33.

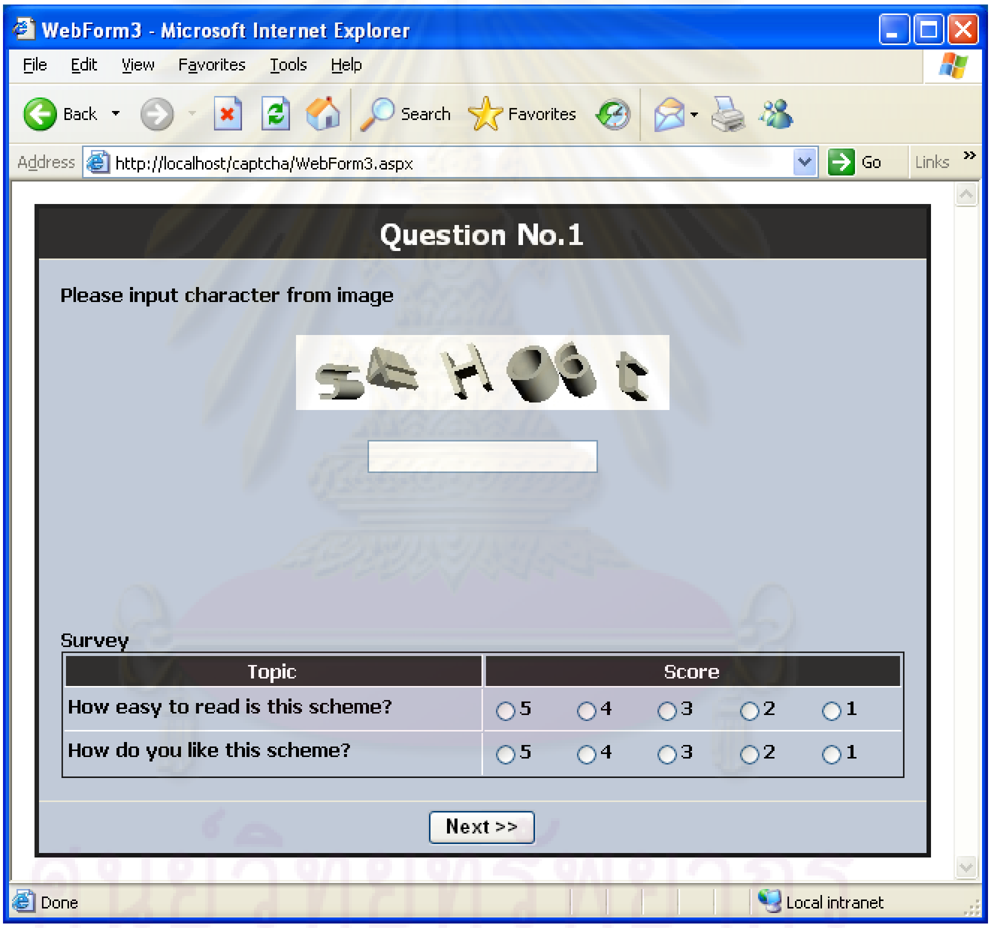


Figure 33. Web Site for Evaluation.

The result of this survey is collected from 138 people with 68 male and 70 female. The survey was comprised of 10 questions. There are ten questions corresponding to ten 3D CAPTCHA methods. For example, question 1 is about 3D CAPTCHA with rotation proposed in the previous section (scheme 1). A survey of usability and preference is also presented in the question.

The web site is used to yield a survey about the readability of our CAPTCHA method. Hit ratio, the percentage of the number of correct recognition by human, is used to measure the efficiency of our 3D CAPTCHA as illustrated in Fig. 34.

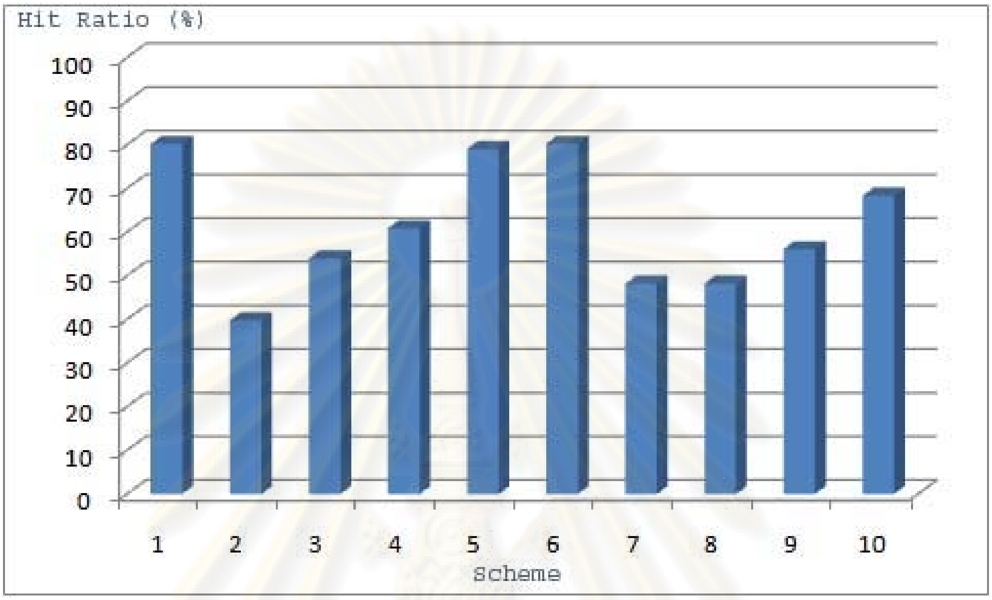


Figure 34. Hit ratio of ten schemes.

The evaluated web site also gets survey about usability and preference of the users. The usability is how easy a string of characters of the considered scheme is to read by human. User can give a score to the CAPTCHA scheme by click a desire score. The score was basically based on 5 points – scale of strongly agree, agree, neutral, disagree and strongly disagree. The result of usability is shown in Fig. 35.

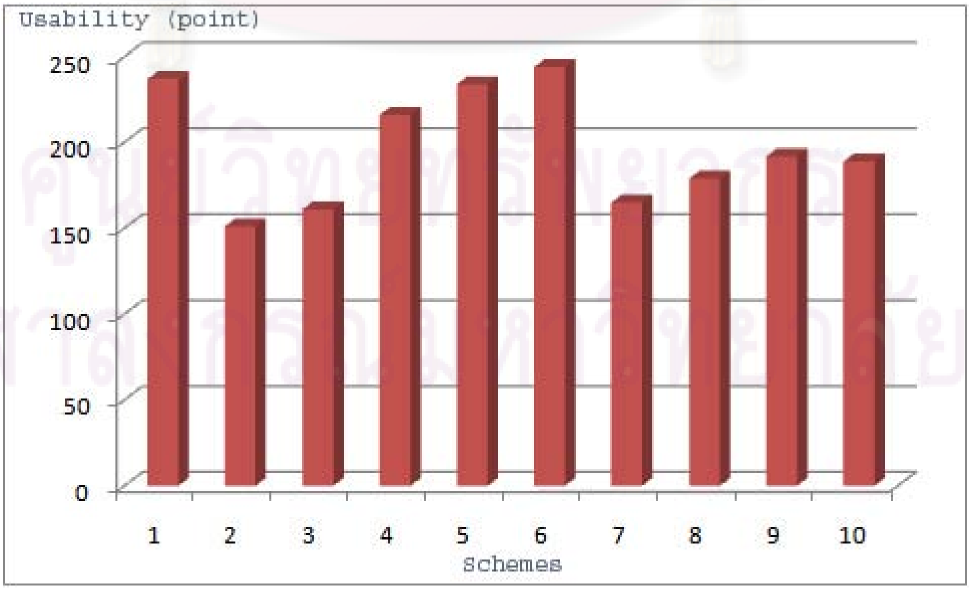


Figure 35. Usability of ten schemes.

The preference is how much user like the considered scheme. The score was also based on 5 points – scale of strongly agree, agree, neutral, disagree and strongly disagree. The result of preference is shown in Fig. 36.

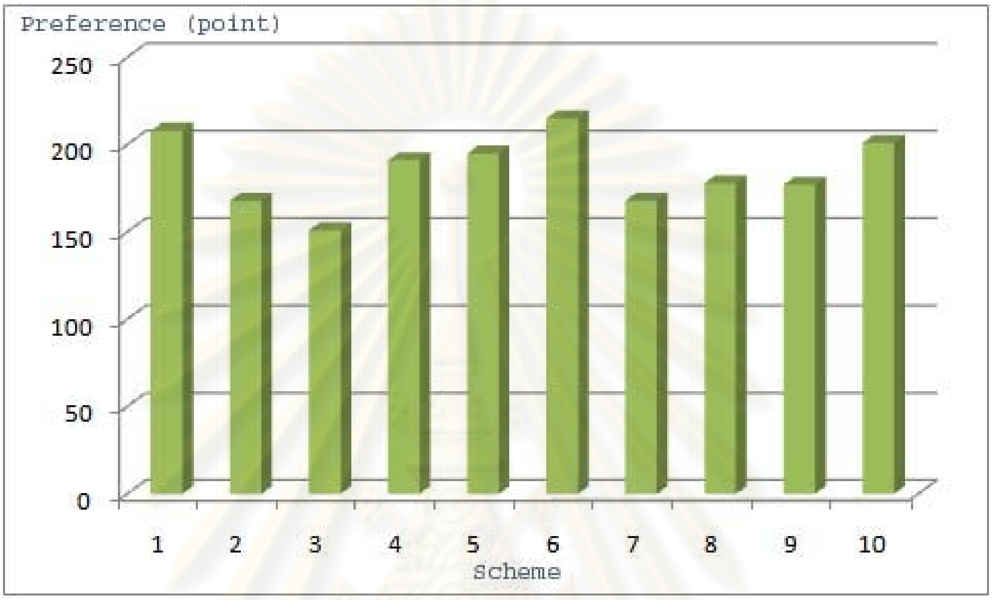


Figure 36. Preference of ten schemes.

Time consuming is added to determine which schemes are difficult to read by users. The lower value means users are easy to read and the higher value means users are difficult to read. The result of the time consuming is shown in Fig. 37.

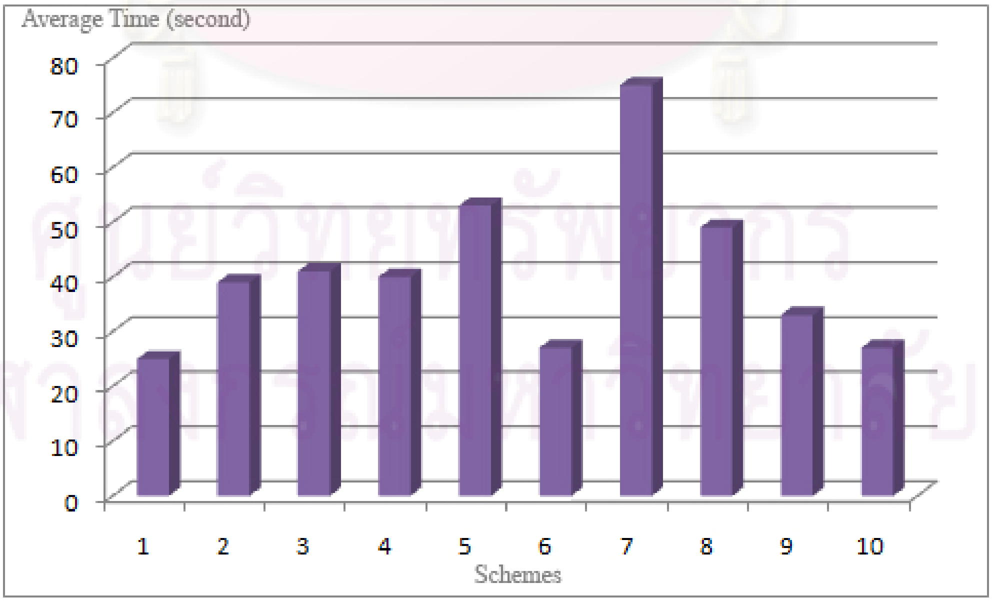


Figure 37. Time consuming.

To find the best scheme, the result of hit ratio, usability, preference and time consuming are equally weighted.

From the result of the hit ratio, usability, and preference, scheme 6 (3D CAPTCHA with rotation and character color variation) is the best from our ten proposed schemes.

6.2 3D Animated CAPTCHA

An implementation of this proposed method is available at http://aspspider.info/huskar. A screenshot of the evaluation web site is shown as Fig. 38.

The result of this survey is collected from 69 people with 45 male and 24 female. The survey is comprised of five questions. Each question is corresponding to the 3D animated schemes mentioned earlier.

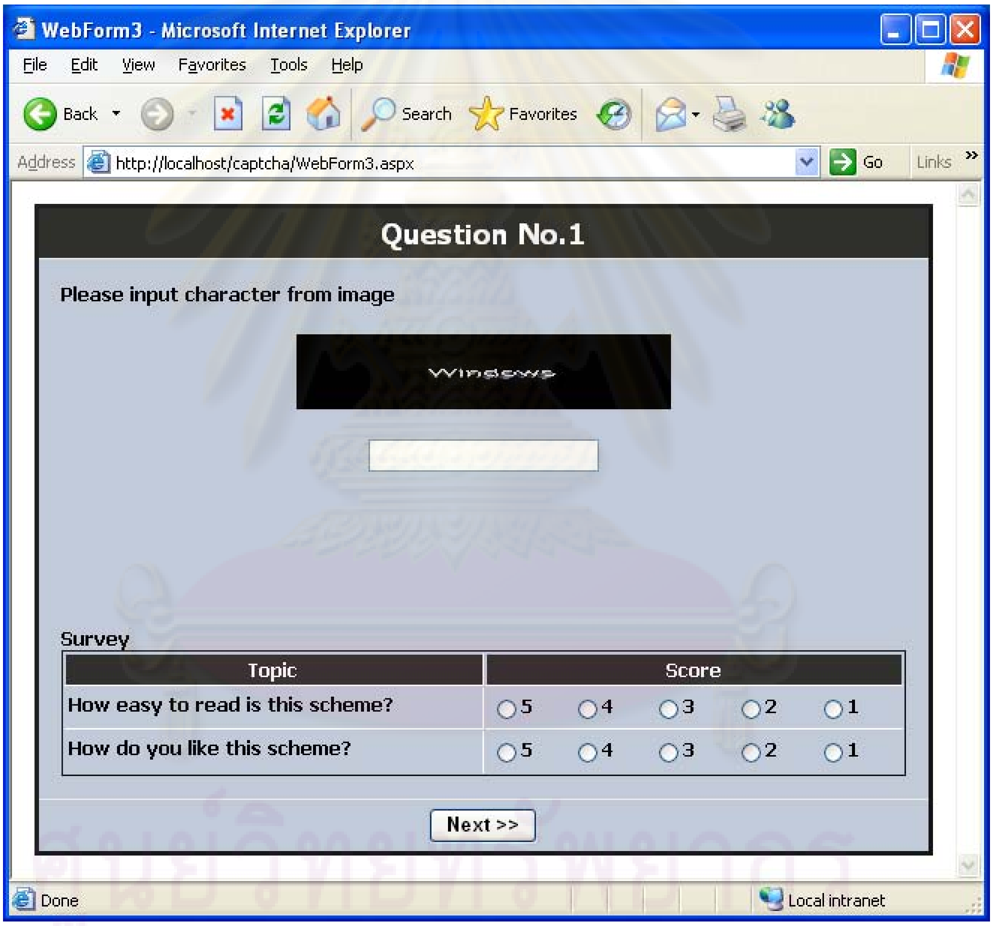


Figure 38. Website for evaluating usability and preference.

The web site is used to yield a survey about the readability of our CAPTCHA method. Hit ratio, the percentage of the number of correct recognition by human, is used to measure the efficiency of our 3D animated CAPTCHA as illustrated in Fig. 39.

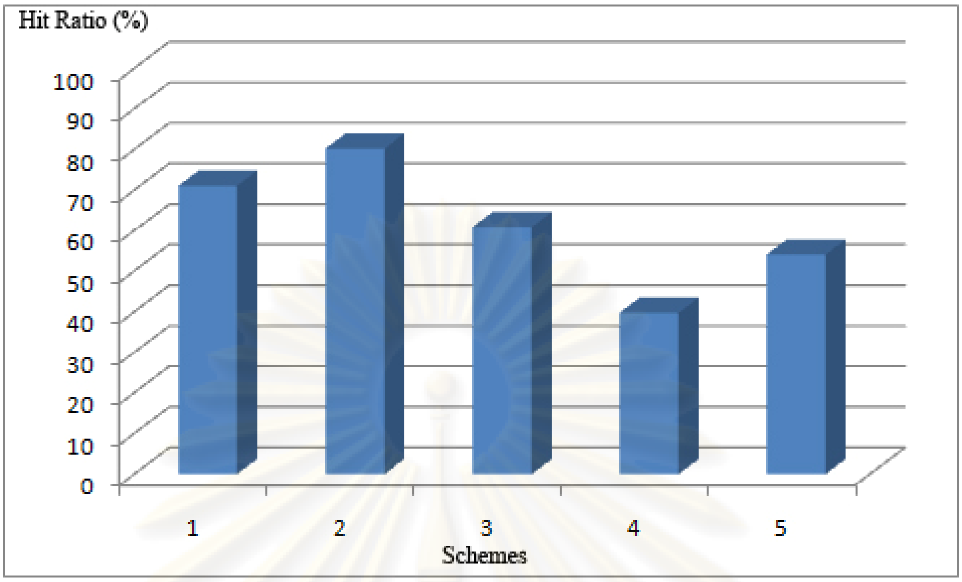


Figure 39. Hit Ratio result.

The evaluated web site also gets survey about usability and preference of the users. The usability is how easy a string of characters of the considered scheme is to read by human. User can give a score to the CAPTCHA scheme by click a desire score. The score was basically based on 5 points - scale of strongly agree, agree, neutral, disagree and strongly disagree. The result of usability is shown in Fig. 40.

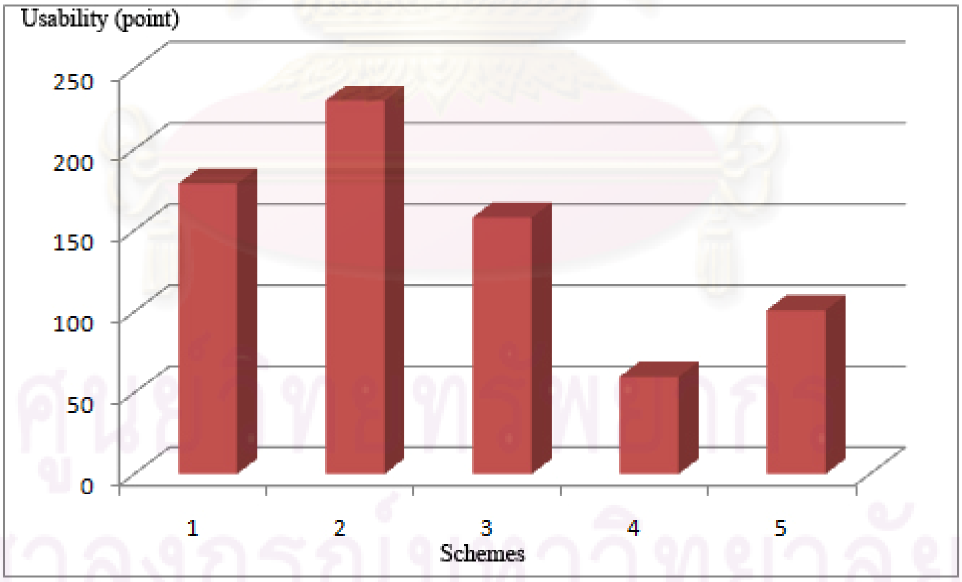


Figure 39. Usability result.

The preference is how much user like the considered scheme. The score was also based on 5 points - scale of strongly agree, agree, neutral, disagree and strongly disagree. The result of preference is shown in Fig. 41.

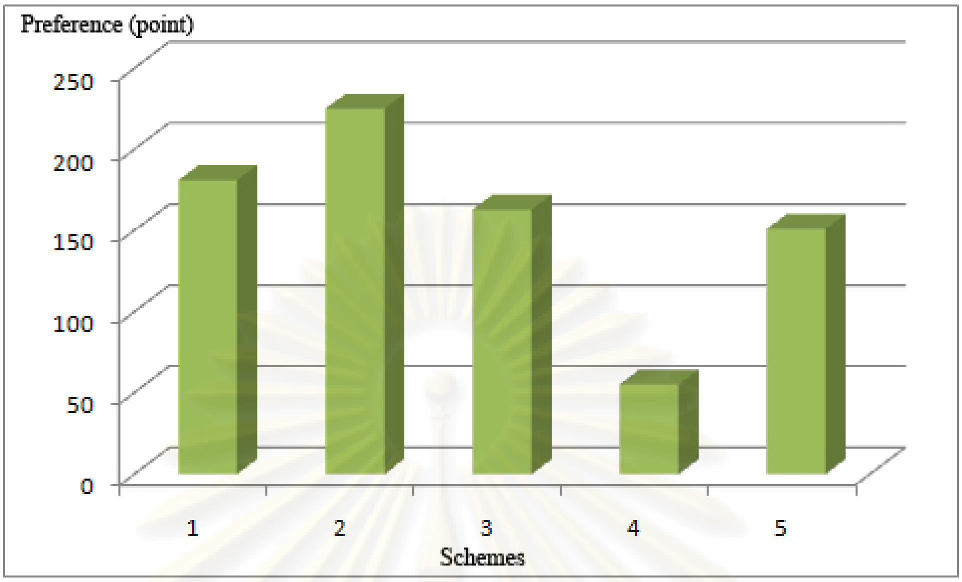


Figure 41. Preference result.

Time consuming is added to determine which schemes are difficult to read by users. The lower value means users are easy to read and the higher value means users are difficult to read. The result of the time consuming is shown in Fig. 42.

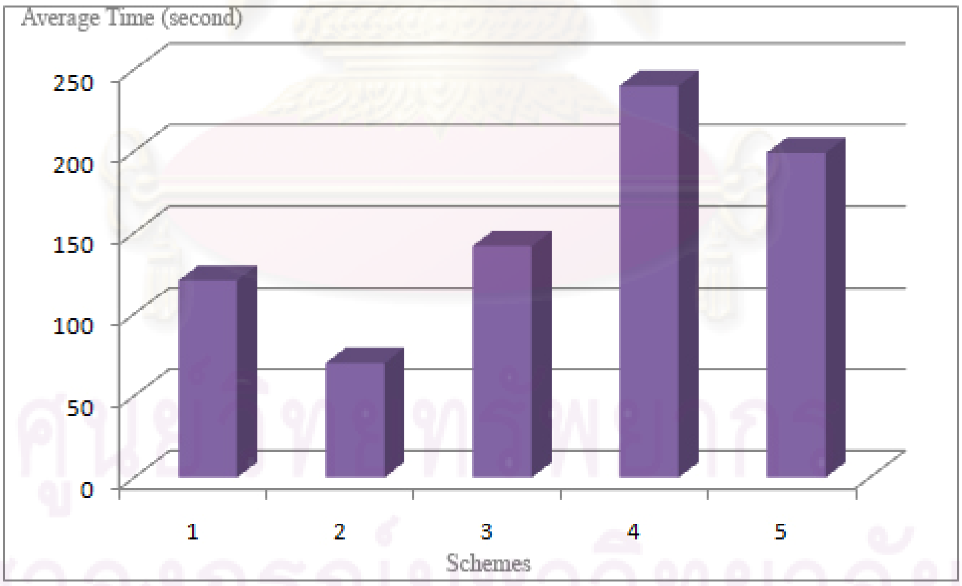


Figure 42. Time consuming result.

To find the best scheme, the result of hit ratio, usability, preference and time consuming are equally weighted.

From the result of the hit ratio, usability, and preference, scheme 2 (3D animated CAPTCHA with one-by-one appearing character) is the best from our five proposed schemes.

CHAPTER VII

DISCUSSION

In this section, the strength of our CAPTCHA method is analyzed in terms of the following:

7.1 Resistance to Pre-Processing

Pre-Processing is the process of removing noise and complicated background from the CAPTCHA image. The background of the 3D CAPTCHA is randomly selected from many forms. Hence, it is difficult to expect which background is used. If the bots attempt to remove the background, then the character is also removed as show in Fig. 43.

Figure 43. Pre-Processing result.

To get a sequence of text, pre-processing is the process of extracting a character from multiple frames of sequential images. The bots will take much time to recognize the CAPTCHA and error prone because it is difficult to expect which frame is used for recognition.

7.2 Resistance to Vertical Segmentation

Vertical Segmentation is the simplest segmentation attack carried out to isolate the characters in the CAPTCHA image to facilitate their recognition. The technique fails because the overlapping factor can be added to make characters overlapping to each other as shown in Fig. 44.

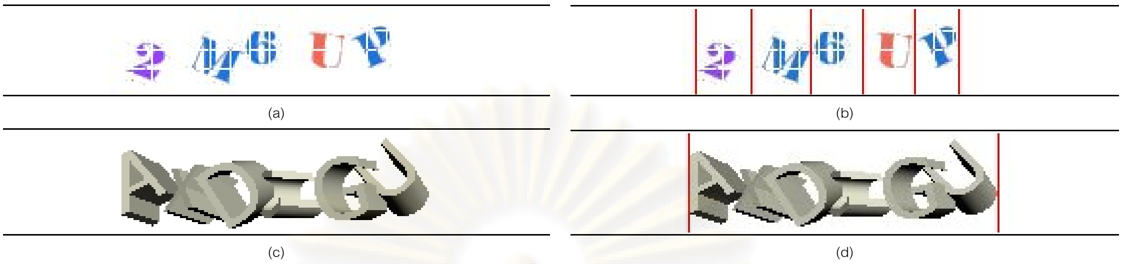


Figure 44. Overlapping Factor added to 3D CAPTCHA.

Vertical Segmentation is the simplest segmentation attack carried out to isolate the characters in the CAPTCHA image to facilitate their recognition. The technique fails because of speed of image sequence. The speed can be automatically adjusted. This causes the bots difficult to segment the characters.

7.3 Resistance to Color-Filling Segmentation

This Segmentation attack involves flood-filling the different connected components of the CAPTCHA image with different colors. The algorithm fails because the characters in our method are fragmented. The result is shown in Fig. 45. As can be seen in the figure, the algorithm identifies many connected components in the same character due to fragmentation of pixels.

Figure 45. Each character containing many connected components.

This segmentation attack uses a color-filling to segment a single character from the CAPTCHA image. It involves flood-filling the different connected components of the CAPTCHA image with different colors. The algorithm fails because the characters in the 3D animated CAPTCHA are more complicated. As seen in Fig. 46, from the traditional CAPTCHA (image of upper row), when red color is applied to the first character. The color is then propagated in the whole area of the first character. This yields the first component that can be used to recognize as the character “s” afterwards. However, when the proposed CAPTCHA (images of lower row) is considered. Since each character contains depth and shading, flood-filling generates too complicate components to recognize.

Figure 46. Examples of flood filling (a) Traditional CAPTCHA (b) Flood-filling with the first character (c) 3D animated CAPTCHA (d) Flood-filling with the proposed CAPTCHA.

7.4 Resistance to Pixel-Count Attack

Although each character has been distorted into a different shape but the pixel counts of foreground color in each character is stall the same. This means that if the bots can segment the CAPTCHA image into individual character. The character can also be identified by pixel count. Our method is not prone to this attack because the pixel count of the character is changeable with respect to the rotation angles in three axes. Table III shows a number of pixels of a character “A” for various angles.

TABLE III. Pixel count of character “A”.

Character	Angle (degree)			Pixels Count
	X	*Y*	*Z*	
	0	0	0	505
	15	0	0	574
	30	0	0	598
	45	0	0	595

Although each character has been distorted into a different shape but the pixel counts of foreground color in each character is still the same. This means that if the bots can segment the CAPTCHA image into individual character. The character can also be identified by pixel count. The 3D animated CAPTCHA is not prone to this attack because the pixel count of the character is changing in every frame.

7.5 Resistance to Character Recognition by using OCR

OCR is a software tool for converting printed materials into text or word processing files that can be easily edited and stored. This tool is used to recognize a character after segmentation has been done. ABBYY FineReader 10 [22] is chosen to test this resistance. Scheme 1 is selected to be test because all other schemes are based on scheme 1 and share the same properties that inhibit OCR recognition.

In the calculation of recognition per character, the 100 CAPTCHA images, each of which contains single CAPTCHA character, are prepared and tested with OCR. For the calculation of recognition per word, the 100 CAPTCHA images, each of which contains six characters, are prepared and tested with OCR. From both of those, the number of recognitions is interpreted into the percentage of accuracy. The result is shown in Table IV.

TABLE IV. OCR result.

Recognition Type	Recognition Result (percent)
Recognition per Character	5 %
Recognition per Word	0 %

OCR is a software tool for converting printed materials into text or word processing files that can be easily edited and stored. This tool is used to recognize a character after segmentation has been done. OCR is significantly more trouble to recognize the 3D animated CAPTCHA because of a variety of fonts, randomly viewing angle and three-dimensional effects.

7.6 Resistance to Dictionary Attack

Dictionary Attack is a technique that uses words from dictionary to break the CAPTCHA. Use of dictionary words makes analysis much easier. When OCR can extract the majority of the characters, it is a simple matter to run the result through a spell checking library and choose the most likely suggestion. This is especially true as the words get longer. This technique fails because the characters are randomly generated from alphanumeric characters that including the letters and the numbers.

Dictionary Attack is a technique that uses words from dictionary to break the CAPTCHA. Use of dictionary words makes analysis much easier. When OCR can extract the majority of the characters, it is a simple matter to run the result through a spell checking library and choose the most likely suggestion. This is especially true as the words get longer. This technique fails because the characters in the 3D animated CAPTCHA are randomly generated from alphanumeric characters that including the letters and the digits.

CHAPTER VIII

CONCLUSION

In this thesis, we propose a new generation of the CAPTCHA method that uses 3D character instead of 2D character. This method based on assumption that human can recognize 3D character image better than Optical Character Recognition (OCR) software bots.

The advantage of using 3D characters in the CAPTCHA is it can recognizable by human users and difficult to read by bots. Our new 3D CAPTCHA method use a same input method similar with the other many well known web sites and services where users type some keywords or characters into an input box. Thus it is easy to learn and use by any user. The algorithm of this method makes it hard to read by OCR programs which mean that it is more secure.

We can increase the rate of its difficulty in order to improve its resistance against the attacks by applying other effects such as increase the length of the CAPTCHA, increase the rotation angle, or include more special characters.

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VITAE

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