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Mobile random text-based voice authentication for older adults: A pilot study

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ABSTRACT

Thai older adults often struggle to use existing smartphone authentication systems due to age-related problems. Random text-based voice authentication, which resists Replay attacks and reduces the need to memorize information, is a suitable alternative. Nevertheless, past studies have insufficiently focused on usability, leading this research effort to improve the usability of voice authentication for older adults. As part of the research, this study seeks to develop a random text-based voice authentication suitable for older adults. The prototype was implemented as a mobile application, VAuth, with Voice User Interface (VUI) as a primary interaction method. Formative Usability Testing was conducted iteratively and incrementally to evaluate and refine VAuth. The first version of VAuth was well-received despite initial problems, which were resolved subsequently. Overall results indicated that VAuth is usable for older adults. Participants could complete all given tasks (enrollment and verification) through VUIs. They responded favorably to VUIs in general and acknowledged their advantages. Moreover, the results from the SEQ and SUS questionnaires aligned with participants' positive opinions. The dialogue design was adequate, and older adults could correctly pronounce Thai-word passphrases in most cases. While the accuracy of Thai speech recognition remains an issue, progress in voice recognition may eventually overcome it. Despite these encouraging results, this study still has limitations. While the test helped determine if VAuth is a viable solution, it did not confirm whether VAuth remains usable when deployed in larger, different contexts, such as a noisy environment or public places. Thus, further studies are needed to compare VAuth with existing authentication methods with an enlarged sample size in multiple usage scenarios.

Keywords: Authentication, Voice authentication, Smartphone, Older adult

INTRODUCTION

Background

Smartphones have become an essential device for the older Thai population. However, they often face challenges in using smartphone authentication systems due to multiple age-related problems [1] and limitations of existing methods. Consequently, many older adults resort to insecure practices such as disabling authentication systems. Thus, this research is part of an effort to overcome these problems by finding a suitable alternative for older adults.

Voice authentication, the technique to verify users' claim of identity from unique features of their voice, is among the promising alternatives, and much progress has been achieved over the years, such as new feature extraction technique [2], utilizing deep learning [3], and security measure against injection of inaudible/hidden commands [4].

However, many studies primarily focus on improving voice authentication accuracy and security. At the same time, the system's usability receives less attention. Thus, the research's primary goal is to improve voice authentication so that it is secure and usable for older adults whose requirements are more restrictive than those of younger users. This study is part of the research and aims to develop a random text-based voice authentication system, utilizing lessons learned from past studies.

Random text-based voice authentication

One potentially suitable voice authentication for older adults is the random text-based system. The main idea is that the system provides a random text that a user will read aloud. Suppose the recognized text is the same as the provided text, and the voice matches the enrolled user. In that case, the user's identity claim is verified.

Random text can be numeric sequences, alphanumeric sequences, or common words. For example, the work of Yan and Zhao [5] presented a voice authentication system where users read a randomly

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generated 6-character pattern code aloud. Bella et al. [3] also proposed a comparable system model using one-time password (OTP) digits in Bahasa Indonesia. Rehman and Lee [6] chose a different approach and introduced a random text-dependent voice-based smartphone authentication protocol. Users read one of five possible English words randomly displayed in each login attempt.

Like traditional one-time text passwords [7], the main advantage of random text-based voice authentication is resistance to Replay Attacks [8]. Successful authentication requires matching text and voice, so the attacker will face difficulties preparing a speech sample that matches the randomly chosen text. Furthermore, the random text-based system reduces users' burdens in memorizing information since they only need to speak a text the system selects.

Nevertheless, there are still problems in these past works, like the user-friendliness of random numeric and alphanumeric codes. Furthermore, these proposed systems have limited usage for Thai subjects, who are often not fluent in foreign languages. Therefore, this research aims to design a usable random text-based voice authentication for Thai older adults.

Using numeric [3] and alphanumeric [5] sequences can pose challenges to older adults. Reading aloud already requires working memory, which is low capacity and volatile. Moreover, age-related deterioration is the most visible in working memory [1], and older adults read aloud more slowly and make more errors than younger adults [9]. Therefore, using complex numeric or alphanumeric sequences will negatively impact older users' experience with the system. On the other hand, using common words, like the system of Rehman and Lee, appears to be more appropriate. Especially if they are the words older adults are familiar with, their performance in reading aloud will improve significantly [9].

Another problem is related to the Graphical User Interface (GUI). Many past works used GUIs as a primary interaction method for their systems. For example, Yan and Zhao's system [5] Informs users of a pattern code they have to speak through the device's screen. While this approach seems sufficient for younger people, it may not be the best choice for older users.

For instance, older adults usually have vision problems [1], causing myriad challenges when using GUI. As its name suggests, performing tasks via GUI relies on visual comprehension of the provided graphics. Therefore, if users have trouble seeing, their performance in tasks like speed and accuracy will suffer accordingly [10].

Furthermore, many older users lack familiarity with interfaces and controls [10]. Additionally, they may easily be confused when controls work differently from the norm, such as pressing and holding a button [11], which are often required to use advanced functions, such as audio recording.

Due to the limitations of GUIs, Voice User Interface (VUI) is a viable alternative. It is consistently suggested as a more usable interaction method for older adults, particularly novice users [12]. Due to their intuitive interaction, VUIs can be utilized to provide a step-by-step guide [13]. VUIs are also simple, easy to use, and ideal for older users with visual and motor impairments [14]. They can be a substitute method for text entry [10]. Although the novelty of the technology can be a significant obstacle, older adults can overcome it once they become accustomed [15,16].

The work of Chang and Dupuis [17] demonstrates the integration of VUIs and random text-based voice authentication. They propose a 2-step authentication for virtual assistants, where users must correctly speak a random sequence of numbers after voice commands. Despite many slightly negative opinions, the method appears more acceptable once users become aware of the security risks.

With these lessons from past systems, the following requirements are established. The system is a text-dependent voice authentication with VUIs as the primary interaction interface. It is also a random text-based system, utilizing standard Thai vocabulary as a passphrase.

MATERIALS AND METHODS

The new voice authentication is implemented as a mobile application named VAuth. The conceptual framework of VAuth is shown in Figure 1, which consists of six primary components: interfaces (GUI and VUI), processes, speech recognition service, speaker recognition service, passphrase list, and Thai word collection.

VAuth has two processes: Enrollment and Verification, which require speech recognition and speaker verification services. Speech recognition service is meant to identify a word that users have spoken. Meanwhile, the speaker verification service will determine whether the voice VAuth hears belongs to a legitimate user.

The interfaces are the channels for users to interact with VAuth. The voice interface is the primary channel, while the graphical interface will support the voice interface. An internal collection contains Thai words to be selected as a passphrase and stored in the list during enrollment. Then, the selected words in the list will be used during the verification process.

Enrollment is required before users can use the verification function. VAuth will ask users to speak a specific number of words to collect voice samples with the correct pronunciation. As a measure against replay attacks, all words are selected randomly from a predefined list.

In the verification process, VAuth will tell users to speak one of the words chosen during enrollment. The users' identity claims will be verified to see if the

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recognized word matches the chosen word and if their voice matches the recorded data. They have another attempt in the case of rejection. However, VAuth will end the process on the second rejection. In the real-world scenario, users will switch to the default method, such as text passwords.

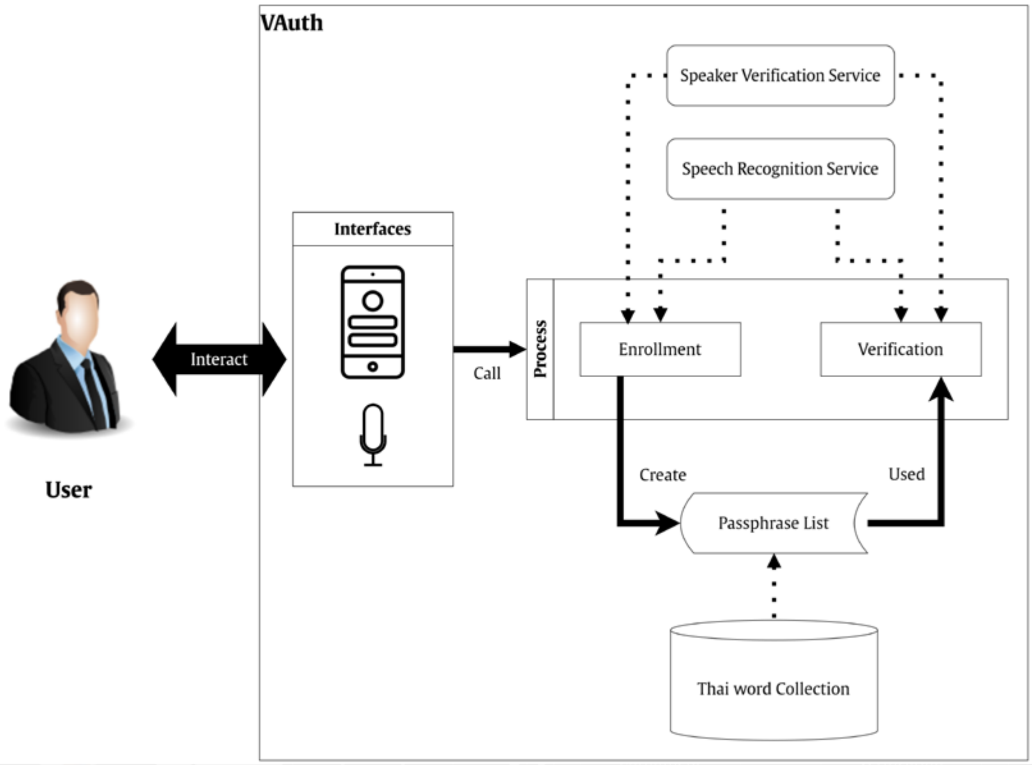

Figure 1 VAuth's conceptual framework.

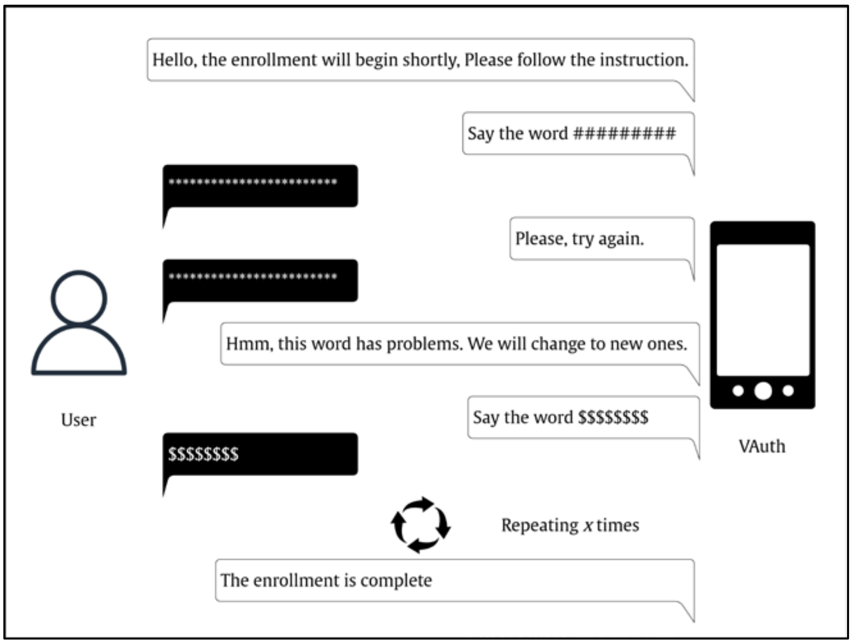

Figure 2 Enrollment dialogue.

VAuth has two primary dialogue flows: enrollment and verification dialogues, designed in line with the guidelines [18] based on Grice's maxims of conversations. Figure 2 illustrates the dialogue for enrollment. When the process begins, VAuth will greet a user and introduce the task he/she is about to perform. Then, VAuth will ask the user to repeat random words one at a time. After the user finishes the task, VAuth will say that voice authentication is ready. If a recognized word does not match one VAuth provides to the user, the system will ask the user to repeat the same word. VAuth will have the user attempt a new word if the second attempt is unsuccessful.

In the verification dialogue shown in Figure 3, VAuth will ask users to speak one of the words selected during enrollment. The system will inform

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users about the result if the verification is successful. However, if either voice or word is incorrect, VAuth will also inform the user, who has another chance for verification.

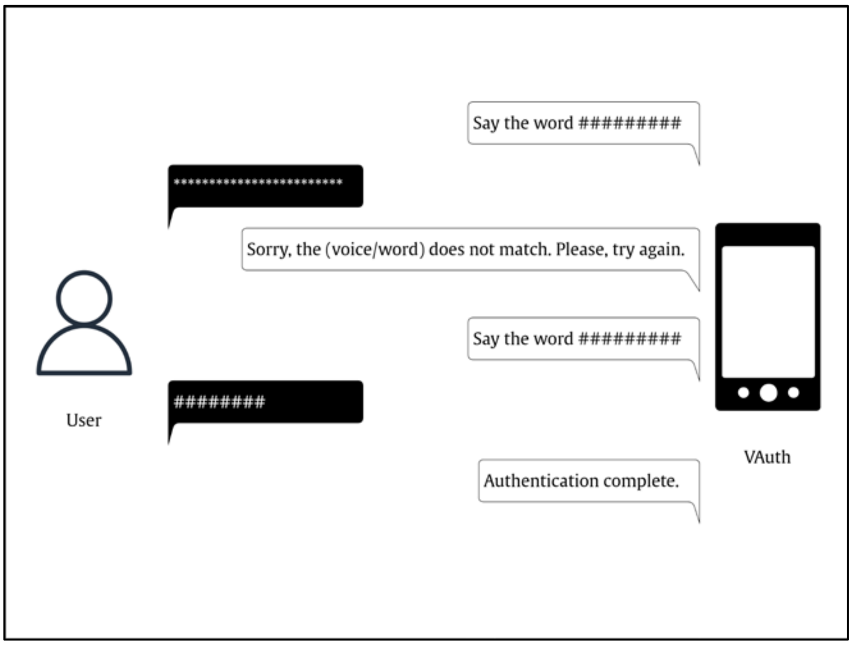

Figure 3 Verification dialogue.

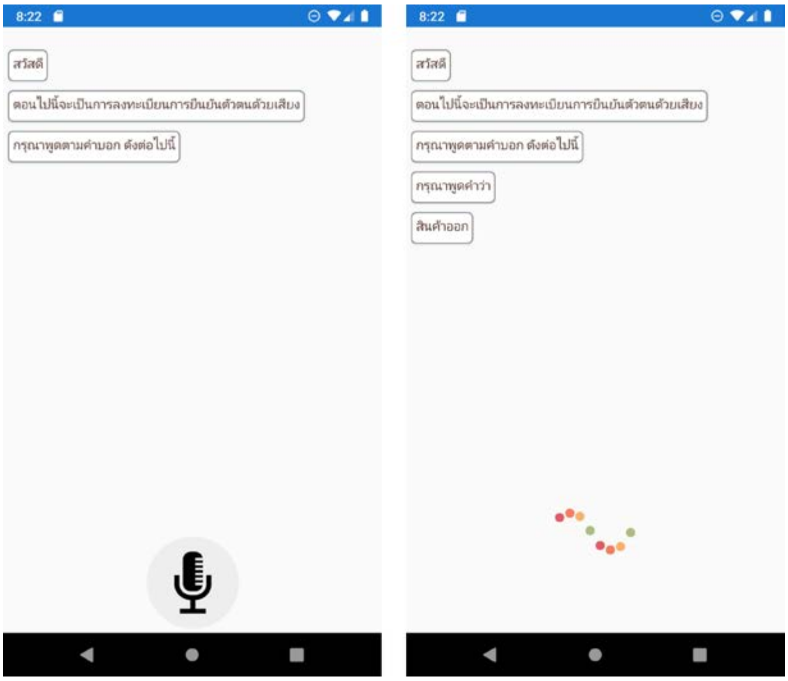

Figure 4 VAuth's GUIs used in the experiment.

A collection of Thai words is prepared for enrollment and verification. However, VUIs place a more considerable burden on short-term memory than the GUI [19]. Moreover, older adults' cognitive decline is most noticeable in short-term memory [1]. Therefore, the words in the collection are relatively short, which minimizes the effort of pronunciation.

The design

The GUIs of VAuth were based on designs for well-known applications, such as Siri and Google Assistant. It consists of a microphone button and a dialogue panel, as illustrated in Figure 4. The microphone button is for users to resume manually, and the panel displays past dialogue, which helps users keep track of the conversation.

VAuth was implemented into an Android application using the Xamarin Mobile app development platform. Both Thai word collection and passphrase list were stored within the application. A speech-to-text service from Microsoft Azure Cognitive Speech Services [20] was used to transcribe texts users have

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spoken because of its relatively good accuracy. Unfortunately, a speaker verification service from Microsoft Azure did not support the Thai language when the study was conducted. Moreover, the proper voice verification system could not be implemented due to time and resource constraints. Nevertheless, since this research focuses on human-computer interaction, this issue was circumvented by simulating the voice verification process and assuming that the speaker's voice always matched the record.

Assessment

Formative Usability Testing [21] was employed for the assessment. Although it typically lacks statistical power due to a small sample group (5-8 persons in general), this approach was suitable for evaluating a new idea and discovering a problem in the early stages.

The testing process was conducted iteratively and incrementally, consisting of three iterations. Participants would perform enrollment and verification with VAuth in each iteration. Participants would receive explanations before beginning the test, and they could use VAuth freely and repeat as many tasks as they wanted. Participants' behaviors and thoughts were noted and later analyzed by researchers to improve the system further. The testing process is intentionally less formal to avoid creating a restrictive atmosphere and encourage participants to express their thoughts.

Participants were recruited from the local community in Don Mueang district, Bangkok. Each testing iteration has five participants. They had to be 60 years old or older and have prior experience regarding smartphone usage. However, experiences in authentication and VUIs were optional. Persons of unsound mind, incompetent, or quasi-incompetent were excluded from participation. The testing was conducted with the cooperation of the local clinic in the same district to select people who fit within the criteria.

Two standardized questionnaires were employed as additional tools to assess the perceived usability of VAuth. The first questionnaire was the Single Ease Question (SEQ) [22], a popular tool to gauge the perceived difficulty of a specific task. The questionnaire typically queries users with a simple question, such as "How easy was it to complete task Number 1?" Users will respond on a scale corresponding to their perceived level of easiness. For this study, a 7-point scale was used; Level One meant the task was very difficult, while Level Seven suggested that the task was very easy.

Another questionnaire was the System Usability Scale (SUS) [23], which measures the perceived ease of use of a system. Figure 5 shows a ten-item questionnaire, each with five scale steps. The odd-numbered items have a positive tone, while the even-numbered items have a negative tone. Participants shall answer how much they agree or disagree with each item, from position one on the leftmost (Strongly Disagree) to position five on the rightmost (Strongly Agree).

	The System Usability Scale Standard Version	Strongly disagree				Strongly disagree
		1	2	3	4	5
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I though the system was easy to use.					
4	I think that I would need the support of a technical person to be abe to use this system.					
5	I found the various functions in the system were well integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very awkward to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could get going with this system.					

Figure 5 SUS Questionnaire.

Scoring the SUS starts with calculating the score for each item. Scores range from zero to four. For items with positive wording (odd-numbered questions), the score is the scale position minus one (e.g., if the response is 3, the score is 2). For items with negative wording (even-numbered questions), the score is five minus the scale position (e.g., if the response is 3, the score is 2). The overall SUS score is obtained by summing

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these item scores and multiplying by 2.5, giving a final score between 0 and 100 in steps of 2.5.

In this research, the modified SUS was used because item five from the original version ("I found the various functions in the system were well integrated") was unsuitable for the study. According to Lewis and Sauro [24], SUS items can be removed if the multiplier used for scoring is adjusted. Instead of the original multiplier of 2.5, the multiplier of 2.78 was used to account for the dropped item, ensuring the final score remained accurate.

The adjective rating from the work of Bangor, Kortum, and Miller [25] was used to interpret and analyze the SUS scores. The rating is described in Table 1.

Table 1 Adjective Rating Scale.

SUS Score	Adjective Rating
< 20.3	Worst Imaginable
< 35.7	Awful
< 50.9	Poor
< 71.1	Okay
< 85.5	Good
< 90.9	Excellent
>= 90.9	Best Imaginable

RESULTS AND DISCUSSION

Participants

In the first iteration, the participants comprised one male and four females aged 64 to 71. One participant held a bachelor's degree, while the rest had an upper-secondary school diploma or equivalent. All participants use Android phones, though the two used no authentication scheme. None of the participants had used VUIs.

Participants in the second iteration were one male and four females, aged between 62 and 76. One participant had a diploma from an upper-secondary school, while four only completed lower-secondary school. Three participants use iPhones, and the other two use Android phones. Two participants had experience with at least one authentication scheme. Two participants had used VUIs in the past.

Finally, participants in the third iteration were one male and four females whose ages ranged from 66 to 75. Only four of them completed lower-secondary schools. Only one participant had the device's authentication feature enabled. Four participants did not have experience with VUIs.

Observation

In the first iteration, while there was awkwardness at the first attempt, participants quickly understood the tasks after receiving instructions. Nonetheless, the system occasionally incorrectly transcribed words. When misrecognition occurred, the participant required assistance from the researcher. During the test, participants completed tasks quietly and would speak only when the researcher talked to them.

There was a minor GUI issue during the second iteration when the conversation was not displayed correctly. The long texts overflowed outside the screen instead of wrapping onto the following line. Regarding user errors, the participants remained idle on multiple occasions after an unsuccessful voice recognition. One participant was unaware that a microphone button was clickable, and another also spoke multiple times before the recording started.

As in the first iteration, the misrecognition Occasionally occurred. For instance, when pronouncing a Thai word with "ส" as an initial, participants had to say the word louder than usual. Otherwise, the system would miss the word entirely. The system also wrongly recognized "ข" as "ข่," the same consonant but with a different tone.

In the third iteration, when failed recognition occurred, Participants could follow the instructions and respond correctly. The problem of speaking too early happened occasionally. Nevertheless, participants made no more mistakes after learning to wait for signals.

Participants' opinions

Participants from the first iteration praised VAuth for its straightforward process with a minimum number of steps. They also had positive opinions about its advantages, such as operating the phone hands-free and its self-intuitive nature. Participants gave additional comments regarding voice authentication. For instance, they stated that most older adults would prefer the old familiar method and might require encouragement from trusted individuals before adopting a new system.

In the second iteration, participants also received VAuth favorably. They noted its quick and uncomplicated process and appreciated that they only needed to follow instructions. Participants also had favorable opinions about the advantages of VUI, such as the hands-free feature. Furthermore, participants like the simplicity of GUIs with minimum controls on the screen.

Likewise, participants in the third iteration had positive opinions about VAuth. They considered it simple and easy to use, with similar reasons to participants in previous iterations. Most participants did not find notable problems in VAuth. Nevertheless, one participant raised concerns about common issues of VUIs, such as noise in the environment and the awkwardness of using VUIs in public places.

Questionnaire

Table 2 shows the SEQ scores rated by participants from all three iterations. Overall, Participants provided high SEQ scores for enrollment and verification tasks, with the lowest score being five.

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The SUS scores are shown in Table 3, along with the Geometric mean of scores in each iteration. The Adjective Rates of the scores are stated in the final column. In line with the SEQ scores, all participants provided relatively high SUS scores. However, the scores from the first iteration are slightly lower than others.

Table 2 SEQ scores.

Iteration	Participant ID	Enrollment	Verification
1st	1	6	6
	2	5	5
	3	6	6
	4	5	5
	5	6	6
2nd	6	6	6
	7	6	6
	8	7	7
	9	5	5
	10	5	5
3rd	11	6	6
	12	5	5
	13	6	6
	14	7	7
	15	6	6

Table 3 SUS scores and adjective rates.

Iteration	Participant ID	SUS score	Adjective Rating
1st	1	78.13	Good
	2	71.88	Good
	3	78.13	Good
	4	56.25	Okay
	5	53.13	Okay
	Geometric Mean	66.61	Okay
2nd	6	87.50	Excellent
	7	87.50	Excellent
	8	81.25	Good
	9	59.38	Okay
	10	62.50	Okay
	Geometric Mean	74.59	Good
3rd	11	84.38	Good
	12	62.50	Okay
	13	90.63	Excellent
	14	87.50	Excellent
	15	68.75	Okay
	Geometric Mean	77.93	Good

System adjustment

During the first iteration, some participants encountered an issue where VAuth confused a word with a similar word having a different tone. Thus, frequently misrecognized words were replaced to remedy this issue.

Unfortunately, these changes did not completely solve the issue, which still occurred in the second iteration. Hence, the mechanism to replace a word after two misrecognitions was introduced to ensure users could complete enrollment. An additional dialogue was also included to guide participants when misrecognition happened. As one participant in the second iteration spoke too early multiple times, voice and vibrating

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notifications were added to signal the start and end of the voice recording period.

The second round of changes eventually mitigated most previous problems. The last remaining issue is accuracy, where misrecognition still occurs. However, there was no further possible adjustment since VAuth relied on a third-party voice recognition service beyond the researchers' control.

Discussions

The results signify the design's suitability for older adults. Participants generally gave positive opinions about VAuth. Their views are supported by SEQ and SUS scores indicating substantial ease of use. Although some problems still occurred during the test, they did not significantly impact user experience and were gradually resolved.

The adoption of VUIs produced encouraging results. While some participants displayed awkwardness due to unfamiliarity, they quickly adapted to VUIs after a brief period. Participants also had favorable opinions about the VUIs, albeit some still had concerns like privacy, security, and user preference. These results are aligned with past works [12-16] and reconfirm the viability of VUIs for older adults.

The dialogues were designed to avoid situations requiring the user's contemplation. All instructions were concise and explicit, while users' responses were limited to speaking passphrases. Although participants did not specifically comment on VAuth's dialogue design, their task completion, high SEQ scores, and lack of criticism meant the dialogues worked as intended, which implied the design approach ' s appropriateness.

Using common Thai words as a passphrase delivered a satisfying outcome. Participants could correctly pronounce almost all passphrases, albeit with some conscious effort. The SEQ scores also indicate a significant ease of tasks. Therefore, it can be concluded that utilizing common words as passphrases, like Rehman and Lee's approach [6], is appropriate with voice authentication.

There is still a persistent issue regarding the accuracy of speech recognition. Although Microsoft's services mostly could recognize the central Thai dialect, there were instances where the service misrecognized words repeatedly, as mentioned previously. The issue raises concerns about whether VAuth can recognize other dialects and accents.

Nonetheless, there has been progress in voice authentication techniques to improve the accuracy of Thai speech recognition. For example, the work of Kantithammakorn et al. [26] proposes a model to assess Thai language fluency and identify patients with mild cognitive impairment. Muangjaroen and Udomsiri's work [27] presents techniques for automatic speech recognition in Thai, with a case study on speech command control of mobile robots. Lastly, Rukwong and Pongpinigpinyo's work [28] applies a deep learning technique to recognize Thai vowels in speech.

Finally, there was another issue about the Think-aloud protocol. According to the protocol, participants will say their thoughts while completing the task. So, researchers can gain insight into the participants' cognitive processes in addition to the outcome. However, older adults rarely spoke during the test, and researchers often needed to ask them questions to get responses after the task.

The explanation is that not all people are comfortable verbalizing their thoughts while occupied with some tasks [29]. In the case of older adults, verbalizing their activities may create a dual-task situation, overloading their already diminished mental capacity and producing inaccurate results. Thus, it is more appropriate to allow older adults to complete the task before verbalizing their thoughts.

CONCLUSIONS

The results of this pilot study suggest that VAuth is usable for older Thai users. Consequently, VAuth's key characteristics, such as VUIs as a primary interface, concise and explicit dialogue, and utilizing Thai words as passphrases, can be considered suitable for older Thai adults. Although there are concerns regarding accuracy, progress has been made in voice authentication techniques to overcome this problem.

Despite encouraging outcomes, this work still has issues. The test does not confirm whether that solution will work when deployed in a bigger context. Furthermore, the test happened in the optimal environment for VUIs, and there are multiple scenarios that this work does not cover, such as the test in environments with various noise levels. Finally, VAuth has yet to be tested against existing authentication methods to confirm its advantages. Therefore, additional studies are necessary to confirm the benefits of VAuth. Those studies will be conducted in other usage conditions to compare VAuth with existing authentication methods with an increasing number of subjects to enable statistical tests.

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