รายงานวิจัยฉบับสมบูรณ์

โครงการ ระบบรู้จำเสียงภาษาคณิตศาสตร์

โดย นางสาววรารัตน์ วงศ์เกี่ย

30 กันยายน 2561

สัญญาเลขที่ TRG5880126

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สังกัด สถาบันนวัตกรรมการเรียนรู้ มหาวิทยาลัยมหิดล

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัยและมหาวิทยาลัยมหิดล

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<u>เอกสารแนบหมายเลข 2</u>

รูปแบบ Abstract (บทคัดย่อ)

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Project Title : ระบบรู้จำเสียงภาษาคณิตศาสตร์

Investigator : นางสาววรารัตน์ วงศ์เกี่ย

E-mail Address : wararat.won@mahidol.edu

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Abstract

We propose an approach to automatically generate two-dimension (2D) mathematical expressions from Thai spoken mathematics language. Due to the rapidly growing world of speech and cloud technology, Python has revealed a library for performing speech recognition, with support for several engines and Application Programming Interfaces (APIs), working both online and offline. It is able to recognize several languages including Thai. We employed this Python library to generate text transcriptions from Thai spoken mathematics recording. Then, we developed a rule-based system to create 2D mathematical expressions from such text transcriptions. More than three thousands mathematical sentences containing variety of symbols, functions, and expressions occurring in a calculus course are split into training and testing data. We hope that the developed system would help in making mathematics accessible to all students, essentially students with visual and physical disabilities.

บทคัดย่อ

งานวิจัยนี้นำเสนอระเบียบวิธีในการสร้างภาษาคณิตศาสตร์ซึ่งประกอบได้ด้วยคำบรรยายภาษาไทยและสัญลักษณ์ทางคณิตศาสตร์จากเสียงพูด ด้วยการพัฒนาอย่างก้าวกระโดดของเทคโนโลยีทางด้านเสียง (speech technology) และเทคโนโลยีแบบหมู่เมฆ (cloud technology) Python ได้พัฒนา library สำหรับระบบแปลงเสียงเป็นข้อความออกมาด้วยการผสมผสานระบบรู้จำภาษาหลาย ๆ ระบบเข้าด้วยกัน ที่สามารถทำงานได้ทั้งออนไลน์และออฟไลน์ สามารถรู้จำเสียงได้หลากหลายภาษารวมถึงภาษาไทยด้วย ผู้วิจัยจึงปรับระเบียบวิธีวิจัยโดยประยุกต์ใช้ส่วนของการแปลงเสียงเป็นข้อความของ Python เพื่อสร้างข้อความจากเสียงพูดภาษาคณิตศาสตร์ จากนั้น ผู้วิจัยพัฒนากฎการแปลงข้อความเหล่านั้นให้เป็นสัญลักษณ์ทางคณิตศาสตร์แบบ 2 มิติ เสียงจากการอ่านข้อความที่ประกอบด้วยเครื่องหมาย สัญลักษณ์และอักขระต่าง ๆ ที่พบเห็นอย่างคุ้นตาในเนื้อหาวิชาแคลคูลัสมากกว่าสามพันข้อความถูกบันทึกจากผู้ให้บันทึกเสียงทั้งชายและหญิงจำนวนเกือบ 200 คน เสียงเหล่านี้แบ่งออกเป็น 2 ส่วน เพื่อฝึกฝนและทดสอบระบบ ผู้วิจัยหวังเป็นอย่างยิ่งว่างานวิจัยนี้จะเป็นประโยชน์ในการเข้าถึงข้อมูลทางคณิตศาสตร์สำหรับทุกคน โดยเฉพาะอย่างยิ่งนักเรียนผู้มีความบกพร่องทางการมองเห็นและการเคลื่อนไหวร่างกาย

Keywords : Speech-to-text, automatic speech recognition, mathematics, Thai spoken mathematic language.

Introduction

To create reports or documents, several text editors and word processors have been developed. With a standard keyboard, those editors allow to present ordinary texts in a linear form, i.e. left-to-right or up-to-down. However, problems with creating mathematical expressions remain the biggest barrier since the appearance of mathematical expressions is in non-linear forms or two-dimension (2D) forms as shown in Figure 1. This mathematical expression presents a summation of a fraction which contains a specific operator ($\sum$) with upper ($\square$) and lower ($\square = 1$) limits, a numerator ($\square^2 - 3$) and a denominator (5) separated by a fraction bar "–", and a superscript which consists of a base ($\square$) and a reduced-size notation (2) placed above and to the right. Inserting the right notations in the right positions to convey the correct meaning of the mathematical expressions is quite tedious and complicated even using mathematical editors, e.g. LaTeX and Math equation of Microsoft (MS) Equation.

$$\sum_{\square=1}^{\square} \frac{\square^2 - 3}{5}$$

Figure 1 An example of non-linear mathematical expressions.

In using markup language, i.e. LaTeX, to create a visual appearance of mathematical expressions, the textual ordered notations as shown in Figure 2 are required as an input. This code is an unfamiliar format that ordinary users need an extra knowledge to understand what each notation means.

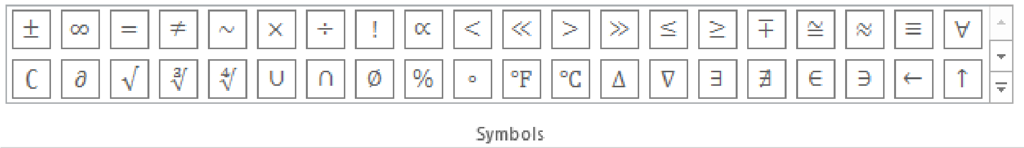
```
\[
    \sum_{i=1}^n \frac{{i^2}-3}{5}
\]
```

Figure 2 An example of LaTeX input.

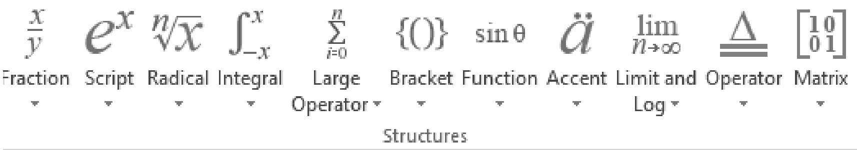
The input LaTeX code is compiled to obtain the corresponding mathematical expression (Figure 1) later on. Not only knowing notations is required for creating the mathematical expression but also ordering of each notation is referred to the meaning of the expression. Moreover, steps of typing and displaying of LaTeX are separated. This mathematical expression is not displayed in the readable form during typing in. Thus, the users cannot immediately see what and where a mistake occurs. It is uncomfortable and time consuming to switch from a typing mode to a displaying mode as well.

Mathematical editors for word processors (e.g. MathType, Miccrosoft Equation) seem to be easier with a graphic user interface (GUI). Structured templates of notations (Figure 3a) and expressions (Figure 3b) are provided for inserting a notation. Users can see an immediate mathematical expression on a monitor once it is inserted. Appearing of mathematical expressions on the screen can solve the separation of type and display modes of LaTeX. Even though this editor provides a fairly facility to see a mathematical expression during type in, it is still time consuming. To create the mathematical expression illustrated in Figure 1, the order of typing is the same as the notations appear in the monitor. To fully utilize this facility such the providing template of nations, users need to see the monitor and the template for searching the right notation and inserting in the right position, and they need to move hands over the mouse and the keyboard for typing the text they need.

However, this facility seems to be useless to not only visually impaired people since they cannot see anything on a monitor but also physical disabilities since they are uncomfortable to use a standard keyboard and a mouse. It is much more convenient and comfortable if we can speak out load and the corresponding mathematical expressions appear on the paper or on the screen.



(a)



(b)

Figure 3 An example of structured templates for inserting mathematical expressions.

There are attempts to develop speech-to-math (STM) systems which have the capabilities to accept speech input of mathematical expressions and generate the corresponding 2D mathematical expressions. Most success system are for English language such as MathTalk (2006), a web-based application on Opera browser (Hannakovic & Nagy, 2006), CamMath (Elliott & Bilmes, 2007), TalkMaths (Wigmore, Pfluegel, Hunter, Denholm-Price & Colbert, 2010), Mathifier (Batlouni, Karaki, Zaraket & Karameh, 2011) while one system accepts Italian language called LAMPDA (Bernareggi & Brigatti, 2008). Unfortunately, those STM systems do not work with reading or speaking mathematical expressions in Thai language.

Objectives

Our main objective is to discover an alternative approach to generate writing forms of Thai spoken mathematical language.

Procedures

Phase I: Review and study literatures

1. Methods, techniques, and algorithms of available speech-to-math (STM) systems and speech-to-text (STT) systems.

Automatic Speech Recognition (ASR) is the process of automatically generating written text from speech input. The classic ASR procedure consists of three main components: Signal Processing, Decoder, and a set of Knowledge Bases shown in Figure 4 (Huang, Acero & Hon, 2001, pp. 5). The voice or speech input is segmented into suitable frame size and extracted necessary features in the Signal Processing. The Decoder, sometime called Modelling, generates recognition results by consulting Acoustic Model, Dictionary, and Language Model that were constructed from a speech corpus. The Acoustic Model consists of the representation of knowledge about acoustics, phonetics, dialect differences among speakers. The Dictionary provides pronunciations of all words found in The Language Model. The Language Model includes a knowledge representation of word-, syllable-, or phone- level structures. Finally, the Decoder provides the word sequence of the speech input.

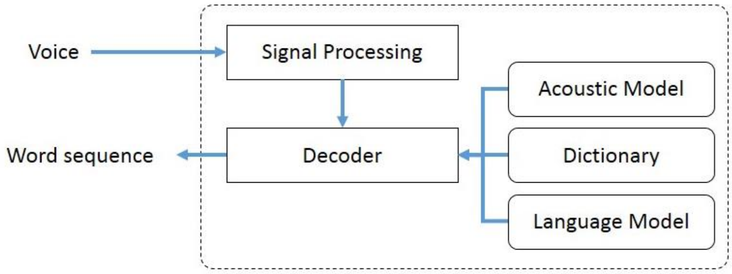


Figure 4 An architecture of automatic speech recognition

Research and development of ASR dates back to 1970s until now. Also, there have been attempts to develop ASR for Thai language since 1987. Speech recognition systems can be classified based on types of utterances: isolated words, connected words, continuous speech, and spontaneous speech. For Thai language, the development of ASR also started with isolated words, e.g. numerals, polysyllabic words, and followed by connected word recognition with minimum pause between words. Finally, continuous and spontaneous speech recognition is taking places by extending vocabulary continuous speech corpus to build acoustic and language models.

In Signal Processing, the speech signals are analyzed and determined how speech signals are naturally produced, what parameters make each signal for unit sounds be different, where the starting points and endpoints of the signals are, and so on. These information can benefits to segment steam of speech input into small units of sound, and to extract necessary features for further recognition processes. For feature extraction, several signal processing techniques are applied to convert the speech waveform to some types of parametric representation. Desai, Dhameliya and Desai (2013) have reviewed feature extraction techniques for speech recognition including Linear Predictive Encoding (LPC), Mel-Cepstra Frequency Coefficient Extraction (MFCC), Preceptual Linear Prediction Coefficient Extraction (PLP), and Linear Prediction Cepstral Coefficient (LPCC) and concluded that performance of MFCC is superior. Nowadays, it seems that MFCC is the state-of-art of feature extraction for speech recognition.

The Decoder uses both acoustic and language models to generate the word sequences that has maximum probability for the input speech. Gaikwad, Gawali and Yannawar (2010) reviewed modeling techniques for speech recognition, i.e. acoustic-phonetic approach, pattern recognition approach, template based recognition approach, dynamic time warping, knowledge based approach, statistical based approach, learning based approach, artificial intelligence approach, and stochastic approach. The pattern recognition approach (e.g. Hidden Markov Model or HMM) has become the predominant approach for speech recognition in the last six decades including Thai speech recognition (Wutiwiwatchai & Furui, 2007).

In summary, we found that the classic ASR procedure consists of three main components: Signal Processing, Decoder, and Knowledge bases. It seems that MFCC is the state-of-art of feature extraction for the signal processing while the pattern recognition approach (e.g. Hidden Markov Model or HMM) has become the predominant approach for decoder process of speech recognition. Knowledge bases consist of Acoustic Model, Dictionary, and Language Model that were constructed from a speech corpus.

2. CMU Sphinx-4.

CMU Sphinx-4 was developed for researchers or developers to change in any step without effect on other modules. CMU Sphinx-4 is an open source developed by a group of researchers of Carnegie Mellon University. It also provide the applications for training and testing databases of a new language.

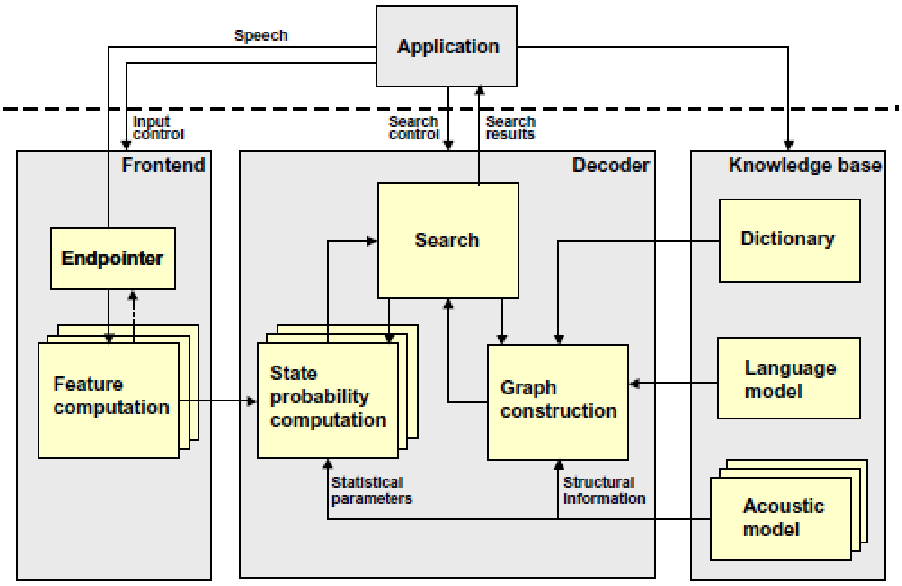


Figure 5 CMU Sphinx-4 architecture (Lamere et al, 2003a).

We concluded overall the CMU Sphinx-4 architecture which are comprises of four main components: Application, Frontend, Decoder, and Knowledge Bases as shown in Figure 5 (Lamere, Kwok, Walker, Gouvêa, Singh, Raj & Wolf, 2003a). This episode of CMU Sphinx-4 was developed for researchers or developers to change in any step without effect on other modules (Lamere et al, 2003b). The Application is designed to control input and output of each step and module.

The Frontend accepts speech input both in audio and video files and from microphone (Walker, Lamere, Kwok, Raj, Singh, Gouvêa, Wolf & Woelfel, 2004), and segments it into small unit speech by determining starting and ending points of unit speech in the Endpointer module. In the Feature Computation, the MFCC or PLP cepstra from segmented speech signal is computed to find out speech parameters or features. Then, a sequence of features is provided for further processing.

In the Knowledge Bases, Dictionary, Language Model, and Acoustic Model are provided. Dictionary are a list of pronunciations found in Language Model corresponding with sequence of word or sub-word units found in Acoustic Model. Linguistic constraints or grammar are translated in forms of context-free grammar (CFG), N-gram language models, or finite state machine in the Language Model. The Acoustic Model is a mapping between a unit of speech and an HMM state that can be scored against incoming features provided by the Frontend.

The main recognition process is the Decoder which completes its task with three modules: State Probability Computation (SPC), Graph Construction (GC), and Search. SPC provides state output density or value to the Search module. This SPC not only computes the state probability from the Acoustic Model but also communicates with the Frontend to obtain the features for which the features of incoming speech must be computed. GC first interprets the Language Model and converts it into an internal grammar. The grammar is represented by a graph which each node is a set of words. Each node is connected by links which have associated language and acoustic probabilities that used to predict likelihood of transiting from one node to another. Grammar nodes are decomposed into a series of HMM states (grammar node $\rightarrow$ word state $\rightarrow$ pronunciation state $\rightarrow$ unit (phoneme, diphone) state $\rightarrow$ HMM state). Each HMM state are connected by language, acoustic, and insertion probabilities associated with them. The Search Module can be performed either depth-first or breadth-first search to find out a tree of possibilities provided by GC module and also use information from the SPC. Pruning is done for returning the best recognition results.

Phase II: Analyze and design the knowledge.

3. All necessary knowledge required in terms of speech and linguistic information

A. A sound-linguistics dictionary and a notation dictionary to be used in pattern matching process.

We created the sound-linguistics dictionary which maps every words into a sequence of sound units. According to CMU Sphinx guideline, we have to prepare this dictionary in forms of the alphanumeric-only phone set. None of a developed Thai phonetic notation system was suitable with CMU Sphinx guideline, Thus, we decided to modify the Thai Romanization system for Thai pronunciations (UNGEGN, 2013) which are alphanumeric only (without special characters, like ':' or '–' or '*' or '/') to be our Thai phonetic natation system. Capital letters are applied for all consonants and vowels. To distinguish between short and long vowels, the first letters of long vowels are double as illustrated in Table 1. Digits (0 - 4) are uses as tone indicators and placed at the end of each syllable (Table 2).

Table 1 Alphanumeric-only phone set for Thai pronunciation.

Thai	Phone	Thai	Phone
Initial Consonants		**Final Consonants**	
บ	B	ก, ข, ฃ, ค, ฅ, ฆ	K
ฎ, ด, ฑ	D	ง	NG
ฝ, ฟ	F	จ, ฉ, ช, ซ, ฌ, ฎ, ฏ, ฐ,	
ห, ฮ	H	ฑ, ฒ, ด, ต, ถ, ท, ธ, ศ,	T
ญ, ย, อย, หย	Y	ษ, ส	
ก	K	ญ, ณ, น, ร, ล, ฬ,	N
ข, ฃ, ค, ฅ, ฆ	KH	บ, ป, ผ, ฝ, พ, ฟ, ภ	P
ล, ฬ, หล	L	ม	M
ม, หม	M	**Cluster Consonants**	
ณ, น, หน	N	ปร, ปล	PR, PL
ง, หง	NG	ตร	TR
ป	P	กร, กล, กว	KR, KL, KW
ผ, พ, ภ	PH	พร, ผร, พล, ผล	PHR, PHL
ร, หร	R	ธร	THR
ซ, ศ, ษ, ส, ทร*	S	คร, คล, คว	KHR, KHL, KHW
ฏ, ต	T	บล, บร	BR, BL
ฐ, ฑ, ฒ, ถ, ท, ธ	TH	ฟล, ฝล, ฟร, ฝร	FR, FL
จ	JH**	ดร	DR
ฉ, ช, ฌ	CH	ดร	DR
ว, หว	W		
อ,	O		

Table 1 Alphanumeric-only phone set for Thai pronunciation. (Cont.)

Thai	Phone	Thai	Phone
Short Vowels ('◌' denotes a consonant character)		**Long Vowels**	
◌ะ, ◌ั◌, ◌รร◌	A	◌า	AA (longer)
เ◌ะ, เ◌็◌	E	เ◌	EE (longer)
แ◌ะ, แ◌็◌	AE	แ◌	AAE (longer)
◌ิ	I	◌ี	II (longer)
โ◌ะ, ◌◌, เ◌าะ, ◌็อ◌	O	โ◌, โ◌◌, ◌อ, ◌อ◌	OO (longer)
◌ุ	U	◌ู	UU (longer)
◌ึ	UE	◌ื, ◌ือ	UUE (longer)
เ◌อะ	OE	เ◌อ, เ◌ิ◌	OOE (longer)
◌ำ	AM	◌รร	AN
เ◌ียะ	IA	เ◌ีย	IIA (longer)
◌ัวะ	UA	◌ัว, ◌ว◌	UUA (longer)
เ◌ือะ	UEA	เ◌ือ	UUEA (longer)
ใ◌, ไ◌, ไ◌ย, ◌ัย,	AI	◌าย	AAI (longer)
เ◌า	AO	◌าว	AAO (longer)
Some vowel with final consonants : 'ย'		**Some vowel with final consonants : 'ว'**	
◌ุย	UI	◌ิว	IO
โ◌ย, ◌อย	OI	เ◌็ว	EO
เ◌ย	OEI	เ◌ว	EEO (longer)
เ◌ือย	UEAI	แ◌็ว	AEO
◌วย	UAI	แ◌ว	AAEO (longer)
Special Characters		เ◌ียว	IAO
ฤ	R UE or R I		
ฤๅ	R UUE (longer)		
ฦ	L UE		
ฦๅ	L UUE (longer)		

* Combination 'ทร' is pronounced as 'S'

** In Thai Romanization system, 'CH' is used for both 'จ' and 'ช'. To easily distinguish between 'ช' and 'จ', we use 'JH' to represent 'จ'.

Table 2 Tone indicators

Digit	Description	Thai – APRAbet symbol – Meaning
0	Mid	ซี – S IY0 – C (English alphsbet)
1	Low	สี่ – S II 1 – 4 (Digit)
2	Falling	ซี่ – S II 2 – unit of teeth
3	High	ซี้ – S II 3 – dead (Chinese loan word)
4	Rising	สี – S II 4 – colour

B. A word type list to be used in identification of different types of words used in reading mathematical expressions.

All words are identified into five types: Thai words (TH), Thai notation words (THN), Thai additional words (THA), loan words (L), loan notation words (LN), and loan additional words (LA). Table 3 shows examples of sound-linguistic dictionary, notation dictionary, and list of word types of five mathematical sentences:

จงหาค่าลิมิตของ $\lim_{□\to 5}\frac{□^2-1}{□+3}$

จงหาค่าลิมิตของ $\lim_{□\to □}\frac{\sin □}{□}$

ให้ $□(□)=\frac{□}{\sqrt{□-1}}$ จงหา $□^{□□}(□)$

จงหาจุดบนพาราโบลา $□=□^2$ ที่อยู่ใกล้จุด (0, 3) มากที่สุด

จงหาปฏิยานุพันธ์ของ $\int_0^{\frac{□}{4}}\sec □\ \tan^2 □\ □□$

Table 3 Examples of sound-linguistic dictionary, notation dictionary, and list of word types.

Sound-linguistic dictionary		Word types		Natation dictionary	
ใกล้	KL AI 2	KL AI 2	TH	KL AI 2	
ของ	KH OO NG 4	KH OO NG 4	THA	KH OO NG 4	
เข้าใกล้	KH AO 2 KL AI 2	KH AO 2 KL AI 2	THN	KH AO 2 KL AI 2	→
ค่า	KH A 2	KH A 2	TH	KH A 2	
จง	JH O NG 0	JH O NG 0	TH	JH O NG 0	
จาก	JH AA K 1	JH AA K 1	THA	JH AA K 1	
จุด	JH U T 1	JH U T 1	THN	JH U T 1	.
ซายน์	S AI N 0	S AI N 0	LN	S AI N 0	sin
เส็ก	S E K 1	S E K 1	LN	S E K 1	sec
ดับเบิ้ลพราม	D A P 3 B OE N 2 PR AA M 0	D A P 3 B OE N 2 PR AA M 0	LN	D A P 3 B OE N 2 PR AA M 0	□□
ดี	D II 0	D II 0	LN	D II 0	D
ถึง	TH UE NG 4	TH UE NG 4	THA	TH UE NG 4	
ทั้งหมด	TH A NG 3 M O D 1	TH A NG 3 M O D 1	THA	TH A NG 3 M O D 1	
ที่	TH II 2	TH II 2	THA	TH II 2	
เท่ากับ	TH AO 2 K A P 1	TH AO 2 K A P 1	THN	TH AO 2 K A P 1	=
แทน	TH AAE N 0	TH AAE N 0	TH	TH AAE N 0	
บน	B O N 0	B O N 0	TH	B O N 0	
บวก	B UUA K 1	B UUA K 1	THN	B UUA K 1	+
ปฏิยานุพันธ์	P A 1 T I 1 Y AA 0 N U 3 P A N 0	P A 1 T I 1 Y AA 0 N U 3 P A N 0	TH	P A 1 T I 1 Y AA 0 N U 3 P A N 0	
พาย	P AAI 0	P AAI 0	LN	P AAI 0	□

Table 3 Examples of sound-linguistic dictionary, notation dictionary, and list of word types. (Cont.)

Sound-linguistic dictionary		Word types		Natation dictionary	
พาราโบลา	P AA 0 R AA 0 B OO 0 L AA 2	P AA 0 R AA 0 B OO 0 L AA 2	L	P AA 0 R AA 0 B OO 0 L AA 2	
มาก	M AA K 2	M AA K 2	TH	M AA K 2	
ยกกำลัง	Y O K 3 K AM 0 L A NG 0	Y O K 3 K AM 0 L A NG 0	THA	Y O K 3 K AM 0 L A NG 0	
วาย	W AAI 0	W AAI 0	LN	W AAI 0	y
ศูนย์	S UU N 0	S UU N 0	THN	S UU N 0	0
เศษ	S EE T 1	S EE T 1	THA	S EE T 1	
ส่วน	S UUA N 1	S UUA N 1	THA	S UUA N 1	
สอง	S OO NG 4	S OO NG 4	THN	S OO NG 4	2
สาม	S AA M 4	S AA M 4	THN	S AA M 4	3
สี่	S II 1	S II 1	THN	S II 1	4
สุด	S U T 0	S U T 0	TH	S U T 0	
หนึ่ง	N UE NG 1	N UE NG 1	THN	N UE NG 1	1
หา	H AA 4	H AA 4	TH	H AA 4	
ห้า	H AA 2	H AA 2	THN	H AA 2	5
ให้	H AI 2	H AI 2	TH	H AI 2	
อยู่	Y U 1	Y U 1	TH	Y U 1	
อินทีเกรต	I N 0 TH II 0 KR EE T 1	I N 0 TH II 0 KR EE T 1	LN	I N 0 TH II 0 KR EE T 1	$\int$
อินฟินิตี้	IN 0 F I 3 N I 3 T II 2	IN 0 F I 3 N I 3 T II 2	LN	IN 0 F I 3 N I 3 T II 2	□
เอ๊กซ์	E K S 3	E K S 3	LN	E K S 3	X
เอฟ	E B F 0	E B F 0	LN	E B F 0	F

4. Speech databases covering expected variety of mathematical expressions to be used as training and test sets.

To produce the higher performance of automatic speech recognition (ASR) systems, the high quality of speech database is needed. Although there are available Thai speech corpus, e.g. LOTUS, and a large-vocabulary continuous speech recognition (LVCSR) (Karnjanadecha, Kimsawad, Chukumnird & Vaithayavanich, 2003; Kasuriya, Sornlertlamvanich, Cotsomrong, Kanokphara & Thatphithakkul, 2003), they did not cover mathematical words for speech-to-math purposes. To develop our Thai mathematical speech recognition, a speech database is designed for speech-to-math purposes. Our speech database need to cover mathematical sentences including Thai words, varieties of symbols, functions, and expressions occurring in calculus course for first-year undergrad students.

Mathematical text sentences were collected from Thai calculus text books containing 3,707 mathematical sentences. There are nearly 1700 words which consists of Thai words and notation words. Haman speech collection were conducted according to the protocol approved by Mahidol University Central Institutional Review Board (MU Central-IRB). To construct speech database, people who have experienced in learning the first-year calculus courses were recruited to voluntarily participate in this research. Each participant was asked to read aloud 15-20 provided mathematical sentences. Their speech were recorded. Figure 6 shows an example of mathematical sentences for one participant.

1. บทที่ 1 ฟังก์ชัน
2. ให้ $A = \{1, 2\}$
3. $B = \{1, 2, 3\}$
4. $A \times B = \{(1, 1), (1, 2), (1, 3), (2, 1), (2, 2), (2, 3)\}$
5. กำหนดให้ $r \subseteq A \times B$ โดย r คือความสัมพันธ์ที่เกิดจากคู่อันดับที่มีสมาชิกตัวหน้าเป็นเลขคู่
6. $r = \{(2, 1), (2, 2), (2, 3)\}$
7. นิยามฟังก์ชัน (Function)
8. ความสัมพันธ์ f จาก A ไป B จะเรียกว่าฟังก์ชันถ้า
9.   1. โดเมนของ f คือ เซต A
10.   2. ถ้า $(x, y) \in f$ และ $(x, z) \in f$ แล้ว $y = z$
11. ให้ $y = f(x) = x^2 + x - 3$
12. D_f คืออะไร และ R_f คืออะไร
13. การพิจารณาโดเมนของฟังก์ชันจะต้องคิดเกี่ยวกับกฎของจำนวนจริง
14. เนื่องจากฟังก์ชันที่เราจะกล่าวถึงเป็นฟังก์ชันตัวแปรจริงส่งไปเป็นค่าจริง $x \in \Re \rightarrow y \in \Re$
15.   1. จำนวนจริงไม่นิยามการหารด้วย 0
16.   2. ภายในรากเลขคู่จะต้องไม่เป็นลบ
17.   3. ฟังก์ชันลอกการิทึมมีโดเมนเป็นบวกเสมอ $\log_a x$, $x > 0$

Figure 6 An example of mathematical sentences.

For preparing speech recording files to be train in CMU Sphinx train module, the recording files must be in MS WAV format with specific rate - 16 kHz and 16 bit in mono single channel for desktop application. An optimal length of audio files is between 5 – 30 seconds while amount of silence in the beginning and in the end of the utterance should not exceed 0.2 second (CMUSphinx, 2015). We collected speeches from people who work for or study at three organizations in Thailand including Mahidol University, Naresuan University, and National Science Museum Thailand. All utterances were recorded according to reading styles.

However, none of handbook nor publications answers out needs to deal with reading mathematical expressions or spoken mathematics in Thai since insufficient background for correctly uttering mathematical expressions in Thai. Thus, we attempt to gather and establish some consistent and well-defined way of reading mathematical expressions in Thai. These spoken mathematics, along with their Thai verbalizations are organized as follows: In Appendix A, the English and Greek alphabets normally used in mathematics are listed. Digits and numbers are listed in Appendix B. The basic symbols used in mathematics are listed in Appendix C. Appendices E-I list the expressions used in some of the more common branches of mathematics. The idea of listing all uttering spoken mathematics in Thai came from Chang (1983).

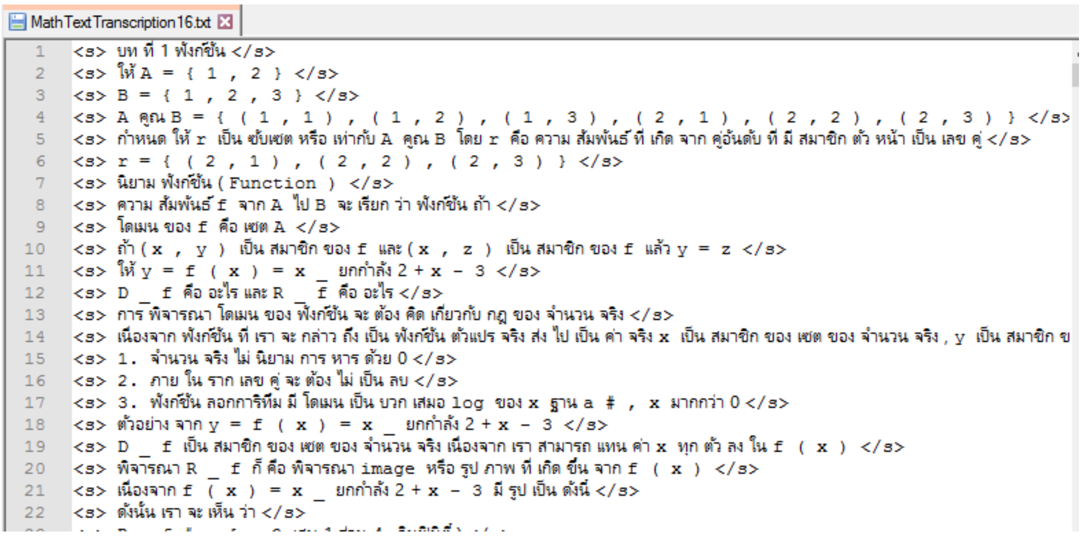
5. The training dataset to be used in constructing Acoustic model which are specific for Thai mathematics spoken language.

Besides concerning the specific properties of recording files (*wav files*), we need to prepare required information of the training database to be extracted statistics from the speech in form of the Acoustic model (CMUSphinx, 2015). SphinxTrain is provided as a toolkit for training an acoustic model. However, the files structure for the database includes a language model, phonetic dictionary, phoneset file, filler dictionary, files_ids files, and transcription files,

A. A language model contain probabilities of the words and word combination. The probabilities are estimated from a sample data in form of the Language model. CMUCLMTK is provided as a toolkit for building a language model. We need to:

- **Prepare a transcription text**

A large collection of clean text is prepared for building the CMU Sphinx statistical language model. The transcription must be a collection of clean text by expanding abbreviations, converting mathematical notations, symbol, and number into words, and cleaning non-word item. All mathematical sentences in the MS word format which comprises both Thai text and mathematical expressions are convert into clean text by using the MathEx Structure Analysis Module of *i-Math* (Wongkia, NaruedomKul & Cercone, 2012). Then, continuous Thai sentences and phrases are segmented by SWATH 2.0 (Klaithin, Kreingket, Phaholphinyo & Kosawat, 2011). In the clean text file, each line starts with <s> and end with </s> as illustrated in Figure 7.


MathTextTranscription16.txt

```
<s> บท ที่ 1 ฟังก์ชัน </s>
<s> ให้ A = { 1 , 2 } </s>
<s> B = { 1 , 2 , 3 } </s>
<s> A คูณ B = { ( 1 , 1 ) , ( 1 , 2 ) , ( 1 , 3 ) , ( 2 , 1 ) , ( 2 , 2 ) , ( 2 , 3 ) } </s>
<s> กำหนด ให้ r เป็น ซับเซต หรือ เท่ากับ A คูณ B โดย r คือ ความ สัมพันธ์ ที่ เกิด จาก คู่อันดับ ที่ มี สมาชิก ตัว หน้า เป็น เลข คู่ </s>
<s> r = { ( 2 , 1 ) , ( 2 , 2 ) , ( 2 , 3 ) } </s>
<s> นิยาม ฟังก์ชัน ( Function ) </s>
<s> ความ สัมพันธ์ f จาก A ไป B จะ เรียก ว่า ฟังก์ชัน ถ้า </s>
<s> โดเมน ของ f คือ เซต A </s>
<s> ถ้า ( x , y ) เป็น สมาชิก ของ f และ ( x , z ) เป็น สมาชิก ของ f แล้ว y = z </s>
<s> ให้ y = f ( x ) = x _ ยกกำลัง 2 + x - 3 </s>
<s> D _ f คือ อะไร และ R _ f คือ อะไร </s>
<s> การ พิจารณา โดเมน ของ ฟังก์ชัน จะ ต้อง คิด เกี่ยวกับ กฎ ของ จำนวน จริง </s>
<s> เนื่องจาก ฟังก์ชัน ที่ เรา จะ กล่าว ถึง เป็น ฟังก์ชัน ตัวแปร จริง ส่ง ไป เป็น ค่า จริง x เป็น สมาชิก ของ เซต ของ จำนวน จริง , y เป็น สมาชิก ข
<s> 1. จำนวน จริง ไม่ นิยาม การ หาร ด้วย 0 </s>
<s> 2. ภาย ใน ราก เลข คู่ จะ ต้อง ไม่ เป็น ลบ </s>
<s> 3. ฟังก์ชัน ลอกการิทึม มี โดเมน เป็น บวก เสมอ log ของ x ฐาน a # , x มากกว่า 0 </s>
<s> ตัวอย่าง จาก y = f ( x ) = x _ ยกกำลัง 2 + x - 3 </s>
<s> D _ f เป็น สมาชิก ของ เซต ของ จำนวน จริง เนื่องจาก เรา สามารถ แทน ค่า x ทุก ตัว ลง ใน f ( x ) </s>
<s> พิจารณา R _ f ก็ คือ พิจารณา image หรือ รูป ภาพ ที่ เกิด ขึ้น จาก f ( x ) </s>
<s> เนื่องจาก f ( x ) = x _ ยกกำลัง 2 + x - 3 มี รูป เป็น ดังนี้ </s>
<s> ดังนั้น เรา จะ เห็น ว่า </s>
```

Figure 7 An example of the clean text file.

- **Generate the vocabulary file which is a list of all the words.**

The language model toolkit for CMU Sphinx, called CUMCLMTK, were used for creating a language model. The output are the language model in ARPA format or in DMP format (*db.lm.DMP*) and the vocabulary file which is a list of all the words in the clean text file and its statistical frequency rate occurring in the language model file (Figure 8). Our database includes 1613 words including numbers and symbols while their statistical correlation between words are shown.

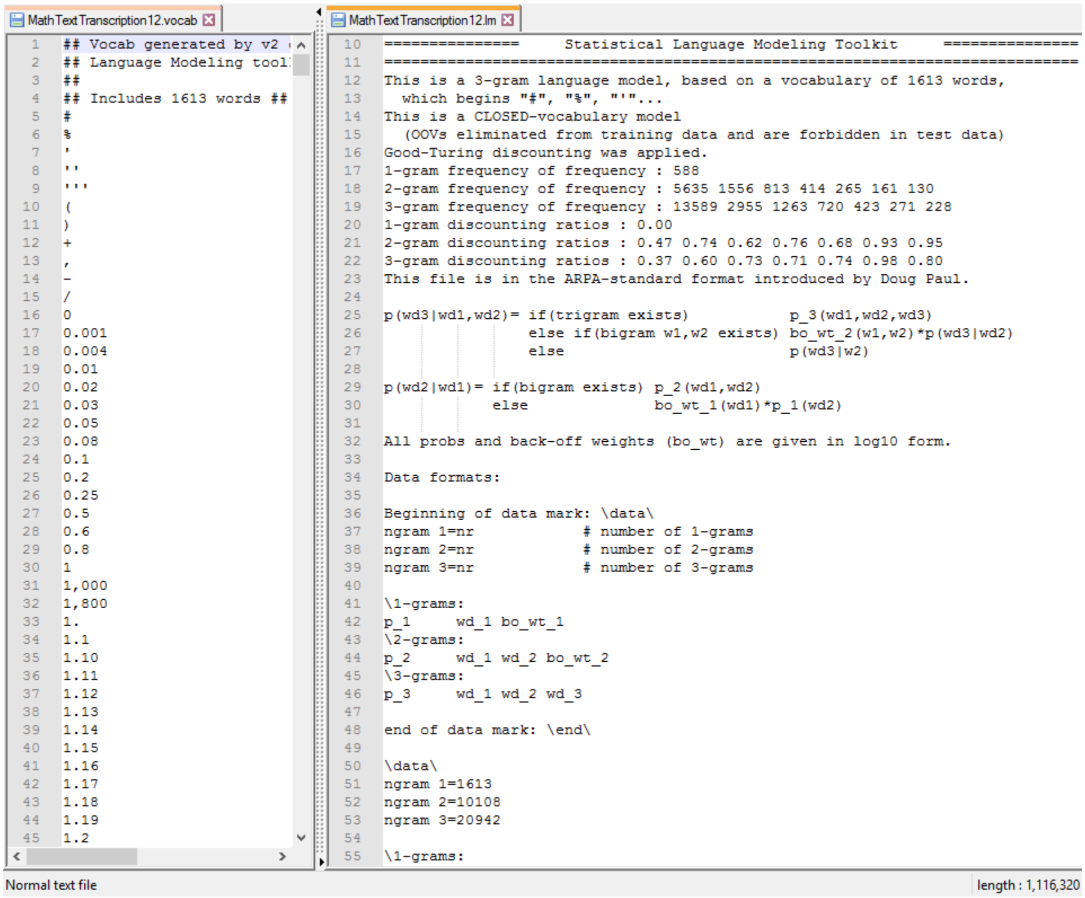


Figure 8 Examples of the language model and vocabulary files.

B. Phonetic dictionary is the list of words and their phonetic transcription. It should have one line per word (*db.dic*). As we mentioned in Section 3, we applied the Thai Romanization system for Thai pronunciations (UNGEGN, 2013) which are alphanumeric only (Table 1 and 2). To build a new dictionary for our Thai mathematical spoken language recognition system, we need to use specialized grapheme to phoneme (g2p) code to do the conversion. Unfortunately, none of available g2p system could convert our Thai word database into the Thai Romanization system for Thai pronunciations. We then found the commercial Thai2English system (Thai2English, 2018) that allows users to create their transliteration schemes (Figure 9) for initial consonants, final consonants, and vowels.

Its output can be used in our sound-linguistics dictionary as illustrated in Figure 10, even though tone indicators are manually refined as:

none (mid tone) – 0

superscript L (low tone) – 1

superscript F (falling tone) – 2

superscript H (high tone) – 3

superscript R (rising tone) – 4

in all transliteration words since we need alphanumeric-only phone set without special characters.

We have tried to contact the Thai2English development team for their purchase version. Unfortunately, their responses broke our heart which informed us that "they will soon have a new and improved version of the downloadable program. In the meantime, the old version is unfortunately temporarily not available."

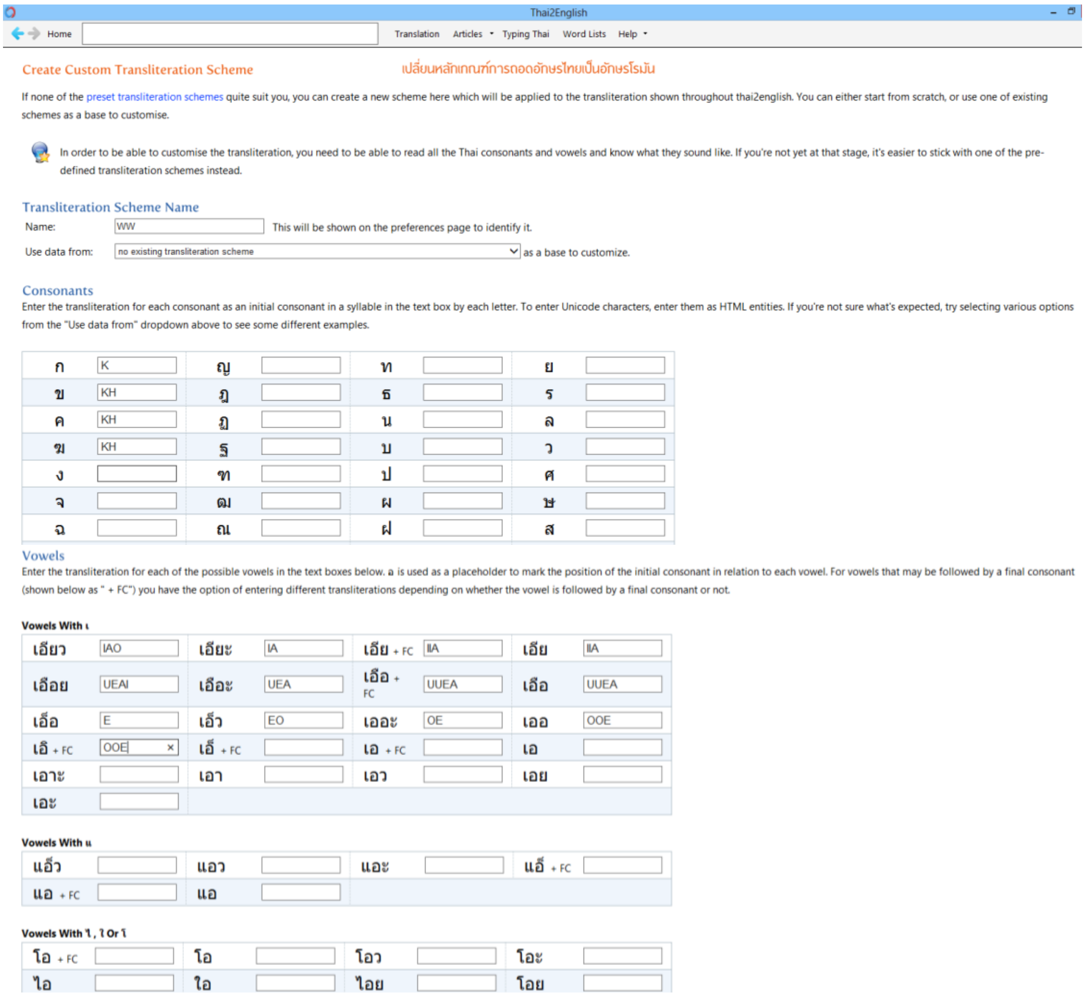


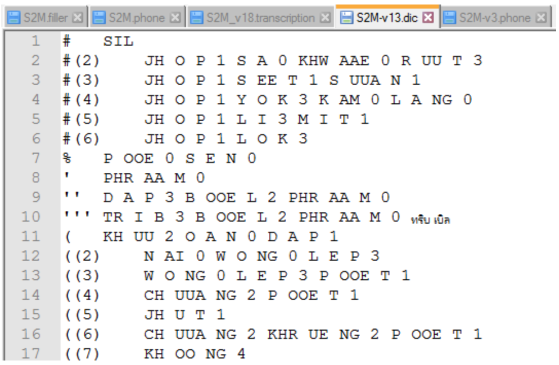
Figure 9 Thai2English interface of transliteration schemes creation.

ความสัมพันธ์ f จาก A ไป B จะ เรียกว่า ฟังก์ชัน ถ้า

KHWAAM SAM^{R} PHAN f JHAAK^{L} A PAI B JHA^{L} RIIAK^{F} WAA^{F} FANG CHAN THAA^{F}

Figure 10 An example of Thai2English transliteration output.

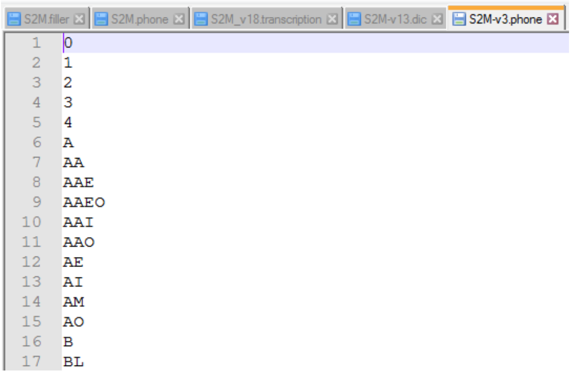
Therefore, the manually process is required to create our effective phonetic dictionary. This process took a lot of time since it required careful and precise conversion by consulting Table 1 and Table 2 illustrated in this report. Anyhow, we could finish it. Examples of our phonetic dictionary show in Figure 11.




```
#    SIL
#(2)     JH O P 1 S A 0 KHW AAE 0 R UU T 3
#(3)     JH O P 1 S EE T 1 S UUA N 1
#(4)     JH O P 1 Y O K 3 K AM 0 L A NG 0
#(5)     JH O P 1 L I 3 M I T 1
#(6)     JH O P 1 L O K 3
%    P OOE 0 S E N 0
'    PHR AA M 0
''   D A P 3 B OOE L 2 PHR AA M 0
'''  TR I B 3 B OOE L 2 PHR AA M 0
(    KH UU 2 O A N 0 D A P 1
((2)     N AI 0 W O NG 0 L E P 3
((3)     W O NG 0 L E P 3 P OOE T 1
((4)     CH UUA NG 2 P OOE T 1
((5)     JH U T 1
((6)     CH UUA NG 2 KHR UE NG 2 P OOE T 1
((7)     KH OO NG 4
```

Figure 11 Examples of the phonetic dictionary.

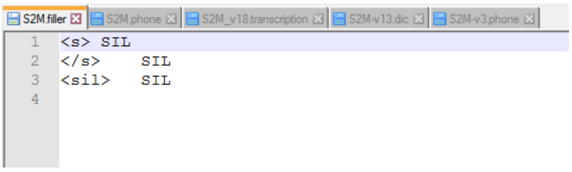
C. **Phoneset file** is the list of phones. It also should have one line per phone (*db.phone*) and the special SIL phone is used to represent a silence sound. Examples of our phonetic dictionary show in Figure 12.




```
0
1
2
3
4
A
AA
AAE
AAEO
AAI
AAO
AE
AI
AM
AO
B
BL
```

Figure 12 Examples of the phoneset file.

D. Filler dictionary contains silences which is non-linguistic sounds like breath, hmm or laugh (Figure 13).




```
<s> SIL
</s>    SIL
<sil>   SIL
```

Figure 13 A filler file.

E. File_ids files are the list of the recording file names one by line. They also must be separately prepared for training and testing datasets (*db_train.fileids* and *db_test.fileids*). The file_ids file contain the path in a file system relative to WAV directory.

F. Transcription files are sequences phonetics and non- speech sounds which list the transcription for each audio file exactly as they occurred in a speech signal. The files must be separated for training and testing datasets (*db_train.transcription* and *db_test.transcription*). Note that *db* is our database name. In the clean text file, each line starts with <s> and end with </s> followed by its audio file name in parentheses without file format or directory.

Since the problems occurred in generating the Phonetic dictionary, the manually generation of transcription file consumed a lot of time as well. In the meantime, we look for another of converting

Thai speech accents into text as well. Finally we found that Python has revealed a library for performing speech recognition, with support for several engines and (Application Programming Interface) APIs working both online and offline. It is able to recognize several languages including Thai. Thus, we spent the rest of the time to study the new released library, speech recognition of Python. In the next section, we will describe how we could apply Python speech recognition library to our research. Form such obstacles, our research schedule have changed.

Phase III: Start our new journey to Python speech recognition library and 2D mathematical expression conversion (Reschedule).

6. Python speech recognition library.

Most existing automatic speech recognition (ASR) systems use hidden Markov models (HMMs) and Gaussian mixture models (GMMs) to deal with the acoustic input. Over the past few years, deep neural networks (DNNs) have been shown outperforming for training acoustic models (Hinton et al., 2012; Hannan et al., 2014). Consequently, Këpuska and Bohouta (2017) compared three speech recognition systems: Microsoft Speech API, Google Speech API, which are commercial ones, and CMU Sphinx-4 which is an open-source system. The word error rate (WER) according to the following equation of each systems were calculated:

$$\text{WER} = \frac{\square + \square + \square}{\square}$$

where I is the number of the insertions,

D is the number of the deletions,

S is the number of substitutions,

N is the number of notations in the references

They concluded that CMU Sphinx-4 achieved 37% WER, Microsoft API achieved 18% WER, and Google API achieved 9% WER.

Fortunately, Python have revealed a package or library, called SpeechRecognition. The SpeechRecognition library is pooled capabilities of several popular speech APIs including CMU Sphinx, Google API, Wit.ai, Microsoft API, Houndify API, IBM Speech-to-Text, and Snowboy Hotword Detection. It is flexible and easy to use for any Python project (SpeechRecognition 3.8.1, 2017). From our exploration of this library. In the recognizer class of this library, they are seven methods for recognizing speech from an audio. We chose the recognize_google() method since it works for Thai even an Internet connection is required.

	A	B
1	บท ที่ 1 ฟังก์ชัน	วันที่ 1 ฟังก์ชัน
2	ให้ A = { 1 , 2 }	ให้ a ใหญ่เท่ากับเซตของ 1 และ 2
3	B = { 1 , 2 , 3 }	B ใหญ่เท่ากับเซตของ 1 2 และ 3
4	A คูณ B = { (1 , 1) , (1 , 2) , (1 , 3) , (2 , 1) , (2 , 2) , (2 , 3) }	ใหญ่หุ่นดีใหญ่เท่ากับเซตของคู่อันดับ 1 1 คู่อันดับ 1 2 อันดับ 1 3 คู่อันดับ 2 อันดับ 2 และอันดับ 3
5	กำหนด ให้ r เป็น ซับเซต หรือ เท่ากับ A คูณ B โดย r คือ ความ สัมพันธ์ ที่ เกิด จาก คู่อันดับ ที่ มี สมาชิก ตัว หน้า เป็น เลข คู่	กำหนดให้ a เป็นสับเซตหรือเท่ากับ a ใหญ่ภูริใหญ่โดย R คือความสัมพันธ์ที่เกิดจากคู่อันดับที่มีสมาชิกตัวหน้าเป็นเลขคู่
6	r = { (2 , 1) , (2 , 2) , (2 , 3) }	R = เซตของคู่อันดับ 2 1 2 2 และ 2 3
7	นิยาม ฟังก์ชัน (Function)	นิยามฟังก์ชันฟังก์ชัน
8	ความ สัมพันธ์ f จาก A ไป B จะ เรียก ว่า ฟังก์ชัน ถ้า	ความสำคัญ f3a ใหญ่ไปบีใหญ่จะเรียกว่าฟังก์ชัน 5
9	โดเมน ของ f คือ เซต A	ข้อ 1 โดเมนของ f คือเซตของอีใหญ่
10	ถ้า (x , y) เป็น สมาชิก ของ f และ (x , z) เป็น สมาชิก ของ f แล้ว y = z	ข้อ 2 5 อันดับ x y เป็นสมาชิกของ f และคู่อันดับ x z เป็นสมาชิกของ x และ Y = Z
11	ให้ y = f (x) = x _ ยกกำลัง 2 + x - 3	ให้ Y = f ของ f = x กำลัง 2 + S Note 3
12	D _ f คือ อะไร และ R _ f คือ อะไร	นิยายห้อย f คืออะไรและอาใหญ่ห้อย f คืออะไร
13	การ พิจารณา โดเมน ของ ฟังก์ชัน จะ ต้อง คิด เกี่ยวกับ กฎ ของ จำนวน จริง	การพิจารณาโดเมนของฟังก์ชันจะต้องคิดเกี่ยวกับกฎของจำนวนจริง

Figure 14 Output of Google recognizer.

3,707 prepared speech recording files in MS WAV format with specific rate - 16 kHz and 16 bit in mono single channel (as described in Section 4) were recognized by Google recognizer of

Python SpeechRecognition library. With the recorded sound qualities, 3,038 sound files could be recognized even some incorrect words were found. 669 files could not be recognized. Figure 14 shows comparison of the Google recognizer outputs (Column B) and text references (Column A).

We have planned to record 669 files that could not be recognized because of the low quality of recording sound. Then, the word error rate (WER) will be calculated. Afterwards, the results of speech recognition will be used to form 2D mathematical expression.

7. Word identification

The recognized results (Column B, Figure 14) contains Thai text, English alphabets, and symbols. For more practical use, the word type list (as shown in Table 3) are re-identified. Since we need to know the boundary of mathematical expression embedded in each recognized text, we identify each word into Thai text (Text) or mathematical expressions (Math). All words in the vocabulary file are labeled as shown in Figure 15. The type of each word is used in the mapping process and forming mathematical expression. The labelled mathematical words are the important information concerning to form mathematical expressions. In the case, a word occurred both in Text and Math. The type of its surrounding words could guide the word is whether Text or Math. If the word is among Math-typed words, it is high probability that the word is in Math rather than Text.

	A	B	C	D	E
1	รูป	เสียง	Text	Math	Note
2	%	เปอร์เซ็นต์	0	1	
3	'	พราม	0	1	
4	"	ดับเบิล พราม	0	1	
5	'''	ทริบเบิล พราม	0	1	
6	(	วงเล็บเปิด	1	1	
7	(	ในวงเล็บ	1	0	
8	(	ช่วงเปิด	0	1	
9	(	ช่วงครึ่งเปิด	0	1	(a,b]
10	(	ของ	0	1	f(x)
11	(	คู่อันดับ	0	1	(1,2)
12	)	วงเล็บปิด	1	1	
13	)	SIL	1	1	
14	+	บวก	0	1	
15	,	ถึง	1	1	(a,b)
16	,	ที่	1	1	
17	,	เมื่อ	1	1	
18	,	โดยที่	1	1	
19	,	และ	0	1	
20	,	SIL	1	1	
21	-	ลบ	0	1	
22	-	ถึง	1	0	
23	/	ต่อ	1	0	
24	:	ต่อ	0	1	
25	:	โดยที่	0	1	

Sheet1

Figure 15 Examples of word identification.

8. 2D mathematical expression conversion

To form mathematical expression, Thai mathematical grammar is needed. Thai mathematical grammar provides the relationship between each element of the notations and words. Their order and position are taken into account. The different expression has different word identification (Wongkia, 2012), for example:

- Fraction: เศษ (/S EE T 1/, numerator), ส่วน (/S UUA N 1/, denominator), and ทั้งหมด (/TH A NG 3 M O D 1/, all)
- Root: รากที่ (/R AA K 2 T I 2/, root) and ของ (/KH OO NG 4/, of)

- Superscript or exponentiation: ยกกำลัง (/Y O K 3 K AM 0 L A NG 0/, to the power) and ทั้งหมด (/TH A NG 3 M O D 1/, all)
- Logarithm: ล็อก (/L 0 K 3/, abbreviation of logarithm), ฐาน (/TH AA N 4/, base)

```
<Identifier> = <mi> {Letter} </mi>;
<Letter> = (Eng_letter | Greek_letter);
<Eng_letter> = (Low_eng | Cap_eng);

<Low_eng> = <a | b | c | d | e | f | g | h | i | j | k | l | m | n | o | p | q | r | s | t | u | v | w | x | y | z>;
<Cap_eng> = <A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y |
        Z>;

<Number> = <mn> {Digit} </mn>;
<Digit> = <0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9>;
<Digit> = <Decimal>;
<Decimal> = {Digit} . {Digit};

<Operator> = <mo> <Binary-op> </mo>;
<Birary_op> = <+ | - | × | ÷ | * | / | = >;

<Power> = <Expression> ยกกำลัง <Expression>;
<Fraction> = เศษ <Expression> ส่วน  <Expression>;
<Square_root> = ราก ที่ สอง ของ <Expression>;
<Root> = ราก ที่ <Expression> ของ <Expression>;
<Logarithm> = ล็อก <Expression> ฐาน <Expression>;

<Expression> = <Identifier | Number | (Number Identifier) | (Identifier Number) | (Expression Operator
        Expression) | (Operator Expression) | Power | Fraction | Square_root | Root | Logarithm>;
```

Figure 16 A set of rules for mathematical expressions.

Figure 16 illustrates a set of rules for mathematical expressions in JSpeech Grammar Format Specification (JSGF) format. The features of JSGF include:

- Using other grammar rules within a grammar rule.
- The OR "|" operator.
- The grouping "(…)" operator.
- The optional grouping "[…]" operator.
- The repeated grouping "{…}" operator.

The Thai mathematical grammar is used to determine the relationship between each element of the notations and words. Figure 17 shows an example of the parsed tree. To display 2D mathematical expression, an eXtensible Markup Language (XML) is chosen since can simply be transformed into various formats including Microsoft Word. XML vocabularies for word-processing documents were defined. It is called the Office Open XML (OpenXML) by EcMA-367 (Paoli, Valet-Harper, Farquhar & Sebestyen, 2006). The mathematical object used in the document is specified by the root tags m:oMath. Each m:oMath is a combination of mathematical elements such as text (m:t), fractions (m:f), and radical objects (m:rad). Examples of relationships between elements of the mathematical object are shown below while the descriptions of each element are shown in Table 4.

<m:oMath>	=	<m:f> | <m:oMath> | <m:r> | <m:rad>
<m:f>	=	<m:num> <m:den>
<m:num>	=	<m:f> | <m:oMath> | <m:r> | <m:rad>
<m:den>	=	<m:f> | <m:oMath> | <m:r> | <m:rad>
<m:rad>	=	<m:deg> <m:e>
<m:deg>	=	<m:f> | <m:oMath> | <m:r> | <m:rad>
<m:e>	=	<m:f> | <m:oMath> | <m:r> | <m:rad>
<m:t>	=	{arbitrary text, e.g., English alphabets, numbers, and math operation signs}

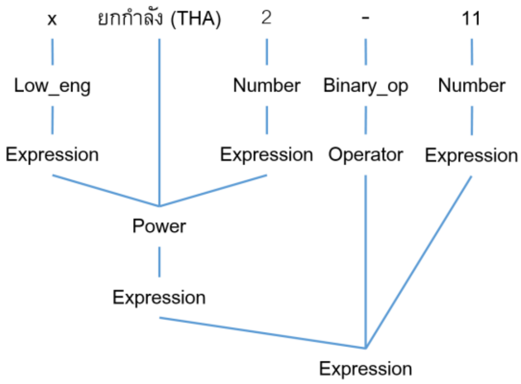


Figure 17 An example of a parsed tree.

Table 4 Mathematical elements and their syntax in XML format (see full details at Paoli et al.,2006).

Features	***Description***	***Parent elements***	***Child elements***
m:deg	Specify the degree in the mathematical radical. This element is optional. When m:deg is omitted, the square root function is assumed.	m:rad	m:f, m:oMath, m:r, m:rad,
m:den	Specify the denominator of a fraction.	m:f	m:oMath, m:r, m:rad,
m:e	Specify the element of several functions including the base of mathematical object, the elements in an array.	m:rad	m:f, m:oMath, m:rad,
m:f	Specify the fraction object, consisting of a numerator and denominator separated by a fraction bar. The fraction bar can be horizontal or diagonal.	m:deg, m:den, m:e, m:num, m:oMath	m:den, m:num
m:num	Specify the numerator of the Fraction object (m:f).	m:f	m:f, m:oMath, m:r, m:rad,
m:oMath	Specify an instance of mathematical text. All mathematical text include equations, expressions, arrays of equations and formulas represented by m:oMath blocks.	m:deg, m:den, m:e, m:num, m:oMath	m:f, m:oMath, m:r, m:rad,
m:rad	Specify the radical object, consisting of a radical, a base (m:e), and an optional degree (m:deg).	m:deg, m:den, m:e, m:num, m:oMath	m:deg, m:e
m:t	Specify the arbitrary text including English alphabets, numbers, mathematical operation sign (e.g., +, –, =, ±), Greek alphabets and so on.	m:r	-

Results and discussion

To develop the accurate and usable Thai mathematical speech recognition system that allow to insert mathematical expression via voice input, we acquired valuable knowledge which contribute to a natural language processing (NPL) field.

A new system of Thai grapheme-to-phoneme (G2P) was generated (described in Table 1 and 2). It is alphanumeric only (without special characters, like ':' or '–' or '*' or '/'). Capital letters are applied for all consonants and vowels. To distinguish between short and long vowels, the first letters of long vowels are double as illustrated in Table 1. Digits (0 - 4) are uses as tone indicators and placed at the end of each syllable.

We also gathered a small speech corpus of Thai mathematical spoken language. More than three thousands mathematical utterances and their pronunciations are in the corpus which covers mathematical expression used in primary school level to university level (described in Section 4).

Since none of Thai governed organizations nor other research groups mentioned about official reading mathematical expression or spoken mathematics in Thai. We presented some consistent and well-defined way of reading mathematical expressions in Thai in Appendices A-I. However, many expression is needed to verify by other experts and audiences (e.g. people who are blind) whether those utterances convey unique and correct mathematical expressions which will be our further investigation.

Since technologies have grown very fast. A small group of researchers could not accomplish a big task in short time comparing to a large group of researchers with full of resources. However, Python SpeecchRecognition package allows a programmer and a developer to use (Section 6). Thus, we overcome several tasks by using Python library to recognize Thai speech.

However, the rule-based for conversing the recognized text into 2D mathematical expression has been developed. Reading mathematical expression in Thai differs from other language. Since we spent a lot of time of this research to develop Thai acoustic model, the evaluation phase could not be finished as proposed in the schedule. Thus, our system will be evaluated the performance of our system with our test dataset in a term of word error rate. The usability of our system in terms of perceived of usefulness and perceived ease of use will be investigated.

Conclusions

Our findings indicate that existing speech recognition modules might be effective enough for recognizing Thai speech. The rule-based conversion is created to convert the recognized Thai text into 2D mathematical expressions. Students, essentially students with visual and physical disabilities can gain benefits of this project.

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Appendices

Appendices are presented spoken mathematics, along with their Thai verbalizations are organized as follows:

Appendix A lists English and Greek alphabets normally used in mathematics.

Appendix B lists digits and numbers are listed.

Appendix C lists basic symbols used in mathematics.

Appendix D lists expressions used in algebra.

Appendix E lists trigonometric and hyperbolic expressions.

Appendix F lists expressions used in logic and set theory.

Appendix G lists expressions used in geometry.

Appendix H lists expressions used in calculus.

Appendix I lists expressions used in linear algebra.

Appendix A English and Greek alphabets.

Notations	Thai	Description	Notations	Thai	Description
A	เอ	-	A	เอใหญ่	-
B	บี	-	B	บีใหญ่	-
C	ซี	-	C	ซีใหญ่	-
D	ดี	-	D	ดีใหญ่	-
E	อี	-	E	อีใหญ่	-
F	เอฟ	-	F	เอฟใหญ่	-
G	จี	-	G	จีใหญ่	-
H	เอช	-	H	เอชใหญ่	-
I	ไอ	-	I	ไอใหญ่	-
J	เจ	-	J	เจใหญ่	-
K	เค	-	K	เคใหญ่	-
L	แอล	-	L	แอลใหญ่	-
M	เอ็ม	-	N	เอ็มใหญ่	-
N	เอ็น	-	M	เอ็นใหญ่	-
O	โอ	-	O	โอใหญ่	-
P	พี	-	P	พีใหญ่	-
Q	คิว	-	Q	คิวใหญ่	-
R	อาร์	-	R	อาร์ใหญ่	-
S	เอส	-	S	เอสใหญ่	-
T	ที	-	T	ทีใหญ่	-
U	ยู	-	U	ยูใหญ่	-
V	วี	-	V	วีใหญ่	-
W	ดับเบิลยู	-	W	ดับเบิลยูใหญ่	-
X	เอ๊กซ์	-	X	เอ๊กซ์ใหญ่	-
Y	วาย	-	Y	วายใหญ่	-
Z	แซด	-	Z	แซดใหญ่	-
Α, α	แอลฟ่า	Alpha	Β, β	เบต้า	Beta
Γ, γ	แกมม่า	Gamma	Δ, δ	เดลต้า	Delta
Ε, ε	เอปซิลอน	Epsilon	Ζ, ζ	ซีต้า	Zeta
Η, η	อีต้า	Eta	Θ, θ	ทีต้า	Theta
Ι, ι	ไอโอต้า	Iota	Κ, κ	เคปป้า	Kappa
Λ, λ	แลมด้า	Lambda	Μ, μ	มิว	Mu
Ν, ν	นิว	Nu	Ξ, ξ	ไซ	Xi
Ο, ο	โอมิครอน	Omicron	Π, π	พาย	Pi
Ρ, ρ	โร	Rho	Σ, ς, σ	ซิกม่า	Sigma
Τ, τ	ทาว	Tau	Υ, υ	อัปซิลอน	Upsilon
Φ, φ	ฟี	Phi	Χ, χ	ไค	Chi
Ψ, ψ	ไซ	Psi	Ω, ω	โอเมก้า	Omega

Appendix B Digits and numbers

Some examples of uttering numbers are shown.

Notations	Thai	Notations	Thai
0	ศูนย์	1	หนึ่ง
2	สอง	3	สาม
4	สี่	5	ห้า
6	หก	7	เจ็ด
8	แปด	9	เก้า
10	สิบ	11	สิบเอ็ด
12	ตั้งแต่ 12-19 อ่านขึ้นด้วยด้วย ‘สิบ’ แล้วตามด้วยตัวเลข เช่น สิบสอง	20	ยี่สิบ
21	ยี่สิบเอ็ด	22*	ตั้งแต่ 22-29 อ่านขึ้นต้นด้วย ‘ยี่สิบ’ แล้วตามด้วยตัวเลข เช่น ยี่สิบห้า
30	ตั้งแต่ 30-90 อ่านขึ้นต้นด้วยตัวเลข แล้วลงท้ายด้วย ‘สิบ’ เช่น หกสิบ	32	ระหว่าง 32-39 จนถึง 92-99 อ่านต้นด้วยตัวเลข ต่อด้วย ‘สิบ’ แล้วตามด้วยตัวเลข เช่น เจ็ดสิบห้า
100	ตั้งแต่ 100-900 อ่านขึ้นต้นด้วยตัวเลข แล้วลงท้ายด้วย ‘ร้อย’ เช่น หนึ่งร้อย	1,000	ตั้งแต่ 1,000-9,000 อ่านขึ้นต้นด้วยตัวเลข แล้วลงท้ายด้วย ‘พัน’ เช่น สองพัน
10,000	ตั้งแต่ 10,000-90,00000 อ่านขึ้นต้นด้วยตัวเลข แล้วลงท้ายด้วย ‘หมื่น’ เช่น สามหมื่น	100,000	ตั้งแต่ 100,000-900,00000 อ่านขึ้นต้นด้วยตัวเลข แล้วลงท้ายด้วย ‘แสน’ เช่น สี่แสน
1,000,000	ตั้งแต่ 1,000,000-9,000,00000 อ่านขึ้นต้นด้วยตัวเลข แล้วลงท้ายด้วย ‘ล้าน’ เช่น ห้าล้าน	11,485, 021	อ่านว่า สิบเอ็ดล้าน สี่แสน แปดหมื่น ห้าพัน ยี่สิบเอ็ด
5.6	ห้า จุด หก	11.78	สิบเอ็ด จุด เจ็ด แปด
$2.\dot{3}$	สอง จุด สาม สามซ้ำ	$10.\dot{5}\dot{3}$	สิบ จุด ห้าสาม ห้าสามซ้ำ
$0.\dot{5}12\dot{3}$	ศูนย์ จุด ห้า หนึ่ง สอง สาม ห้าหนึ่งสองสามซ้ำ	$17.42\dot{5}\dot{3}$	สิบเจ็ด จุด สี่ สอง ห้า สาม ห้าสามซ้ำ

Appendix C Basic symbols

Notations	Thai	Description	Notations	Thai	Description
+	บวก	Plus	-	ลบ ถึง	Minus To
±	บวก ลบ	Plus or minus	∓	ลบ บวก	Minus or plus
×	คูณ	Time, multiplied by	*	ดอกจัน	Star
·	คูณ	Time	÷	หารด้วย	Divided by
/	ทับ	Over, slash	=	เท่ากับ	Equals, equal to
≠	ไม่-เท่า-กับ	Not equal to	∼	- คล้ายกับ - นิเสธ	Be asymptotic to Not
∝	แปรผันตรง	Be proportional to	≅	เท่ากันทุกประการ	Be congruent to
≡	สม-มูล	Equivalent to, identical with	≈	ประมาณ	Nearly equal to
>	มากกว่า	Greater than	<	น้อยกว่า	Less than
≫	มากกว่ามากกว่า	Much greater than	≪	น้อยกว่า น้อยกว่า	Much smaller than
≥	มากกว่า หรือ เท่ากับ	Greater than or equal to	≤	น้อยกว่า หรือ เท่ากับ	Less than or equal to
%	เปอร์เซ็นต์	Percent	°	องศา	Degree
□	องศาฟาเรนไฮ	Degree Fahrenheit	□	องศาเซลเซียส	Degree Celsius
:	ต่อ	To	//, ‖	ขนาน	Parallel to
∴	เพราะฉนั้น	Therefore	…	- ไปเรื่อยเรื่อย - จนถึง	So on
⊥	ตั้งฉาก	Be perpendicular to	∞	อินฟินิตี้	Infinity
∩	อินเตอร์เซ็ก	Intersect	∪	ยูเนียน	Union
⊄	ไม่เป็นซับเซต	Not contained in	⊂	เป็นซับเซต	Be a subset of
⊆	เป็นซับเซต หรือ เท่ากับ	Be not a subset of or equal to	∈	เป็นสมาชิก	Be an element of
∉	ไม่เป็นสมาชิก	Be not an element of	∠	มุม	Angle
∅	เซต ว่าง	Null set	Δ	เดลต้า	
(	วงเล็บเปิด		)	วงเล็บปิด	
[	วงเล็บเหลี่ยมเปิด		]	วงเล็บเหลี่ยมปิด	
{	ปีกกาเปิด		}	ปีกกาปิด	
!	แฟกทอเรียล		⇒	ถ้า...แล้ว...	
⇔	ก็ต่อเมื่อ		∨	หรือ	
∧	และ		∀	ฟอร์ ออล	
∃	ฟอร์ ซัม				

Appendix D Algebra.

The letters are used with the symbol for clarify the expressions

Notations	Thai	Notations	Thai
a + b	a บวก b	a + b + c	a บวก b บวก c
a – b	a ลบ b	- a – b	ลบ a ลบ b
a + b - c	a บวก b ลบ c	a - b – c	a ลบ b ลบ c
a – (b + c)	a ลบ วงเล็บเปิด b บวก c วงเล็บปิด	a – (b - c)	a ลบ วงเล็บเปิด b ลบ c วงเล็บปิด
a – (- b - c)	a ลบ วงเล็บเปิด ลบ b ลบ c วงเล็บปิด	a – (b + c) – d	a ลบ วงเล็บเปิด b บวก c วงเล็บปิด ลบ d
a – b – (c – d)	a ลบ b ลบ วงเล็บเปิด c ลบ d วงเล็บปิด	a × b	- a คูณ b - a ครอส b
a · b	- a คูณ b - a ดอท b	Ab	- a คูณ b - a b
a · - b	- a คูณ ลบ b - a ดอท ลบ b	ab + c	a b บวก c
a (b + c)	a คูณ วงเล็บเปิด b บวก c วงเล็บปิด	a (b + c) + d	a คูณ วงเล็บเปิด b บวก c วงเล็บปิด บวก d
ab - c	a b ลบ c	a (b - c)	a คูณ วงเล็บเปิด b ลบ c วงเล็บปิด
a (- b - c)	a คูณ วงเล็บเปิด ลบ b ลบ c วงเล็บปิด	a (b - c + d)	a คูณ วงเล็บเปิด b ลบ c บวก d วงเล็บปิด
ab + cd	a b บวก c d	ab – cd	a b ลบ c d
a (b + c) – d (e - f)	a คูณ วงเล็บเปิด b บวก c วงเล็บปิด ลบ d คูณ วงเล็บเปิด e บวก f วงเล็บปิด	a [b + c – d (e - f)]	a คูณ วงเล็บเหลี่ยมเปิด b บวก c ลบ d คูณ วงเล็บเปิด e บวก f วงเล็บปิด วงเล็บเหลี่ยมปิด
(a + b) (c + d)	วงเล็บเปิด a บวก b วงเล็บปิด คูณ วงเล็บเปิด c บวก d วงเล็บปิด	$\frac{\square}{\square}$	เศษ a ส่วน b
$\frac{\square + \square}{\square}$	เศษ a บวก b ทั้งหมด ส่วน c	$\square + \frac{\square}{\square}$	- a บวก เศษ b ส่วน c
$\square + \frac{\square}{\square + \square}$	a บวก เศษ b ส่วน c บวก d จบตัวส่วน	$\frac{\square + \square}{\square} + \square$	เศษ a บวก b ทั้งหมด ส่วน c จบตัวส่วน บวก d
$\square + \frac{\square}{\square} + \square$	a บวก เศษ b ส่วน c จบตัวส่วน บวก d	$\frac{\square}{\square} + \frac{\square}{\square}$	เศษ a ส่วน b จบตัวส่วน บวก เศษ c ส่วน d จบตัวส่วน
$\frac{\square}{\square + \frac{\square}{\square}}$	เศษ a ส่วน b บวก เศษ c ส่วน d จบตัวส่วน	$\frac{\frac{\square}{\square}}{\square}$	เศษ a ส่วน b ทั้งหมด ส่วน d
$\frac{\square}{\frac{\square}{\square}}$	เศษ a ส่วน เศษ c ส่วน d	$\frac{\frac{\square}{\square}}{\frac{\square}{\square}}$	เศษ a ส่วน b ทั้งหมด เศษ c ส่วน d

Appendix D Algebra (Cont.).

The letters are used with the symbol for clarify the expressions

Notations	Thai	Notations	Thai
$\frac{\square}{\frac{\square}{\square}}$	เศษ a ส่วน เศษ c ส่วน d	$\frac{\frac{\square}{\square}}{\frac{\square}{\square}}$	เศษ a ส่วน b ทั้งหมด เศษ c ส่วน d
$\frac{\square}{\frac{\square}{\square}}$	เศษ a ส่วน เศษ c ส่วน d	$\frac{\frac{\square}{\square}}{\frac{\square}{\square}}$	เศษ a ส่วน b ทั้งหมด เศษ c ส่วน d
$\frac{\frac{\square+\square}{\square}}{\square}$	เศษ a บวก b ทั้งหมด ส่วน c ทั้งหมด ส่วน d	$\frac{\square}{\square}(\square+\square)$	เศษ c ส่วน d จบตัวส่วน คูณ วงเล็บเปิด a บวก b วงเล็บปิด
$\frac{\frac{\square}{\square}}{\square+\square}$	เศษ a ส่วน เศษ b ส่วน c บวก d	$\square\left(\square+\frac{\square}{\square}\right)$	a คูณ วงเล็บเปิด b บวก เศษ c ส่วน d จบตัวส่วน วงเล็บปิด
$\square+\frac{\square}{\square+\frac{\square}{\square+\frac{\square}{\square+\frac{\square}{\vdots}}}}$	a บวก เศษ b ส่วน a บวก เศษ b ส่วน a บวก เศษ b ส่วน a บวก เศษ b ส่วน เศษ a บวก เศษ b ส่วน ไปเรื่อยเรื่อย	ay + bx + c = 0	a y บวก b x บวก c เท่ากับ 0
y = mx + b	y เท่ากับ m x บวก b	$y = ax^2 + bx + c$	y เท่ากับ a x ยกกำลัง 2 บวก b x บวก c
$\square=\frac{-\square\pm\sqrt{\square^2-4\square\square}}{2\square}$	x เท่ากับ เศษ ลบ b บวก ลบ สแควรูท b ยกกำลัง 2 ลบ 4 a c จบสแควรูท ทั้งหมด ส่วน 2 a	$x^2 + y^2 = r^2$	x ยกกำลัง 2 บวก y ยกกำลัง 2 เท่ากับ r ยกกำลัง 2
$\square=\pm\sqrt{\square^2-\square^2}$	y เท่ากับ บวก ลบ สแควรูท r ยกกำลัง 2 ลบ x ยกกำลัง 2	$(x - h)^2 + (y - k)^2 = r^2$	วงเล็บเปิด x ลบ h วงเล็บปิด ทั้งหมด ยกกำลัง 2 บวก วงเล็บเปิด y ลบ k วงเล็บปิด ทั้งหมด ยกกำลัง 2 เท่ากับ r ยกกำลัง 2
$\frac{\square^2}{\square^2}+\frac{\square^2}{\square^2}=1$	เศษ x ยกกำลัง 2 ทั้งหมด ส่วน a ยกกำลัง 2 จบตัวส่วน บวก เศษ y ยกกำลัง 2 ทั้งหมด ส่วน b ยกกำลัง 2 จบตัวส่วน เท่ากับ 1	$\frac{\square^2}{\square^2}-\frac{\square^2}{\square^2}=1$	เศษ x ยกกำลัง 2 ทั้งหมด ส่วน a ยกกำลัง 2 จบตัวส่วน ลบ เศษ y ยกกำลัง 2 ทั้งหมด ส่วน b ยกกำลัง 2 จบตัวส่วน เท่ากับ 1
$ax^2 + bxy + cy^2 + dx + ey + f = 0$	a x ยกกำลัง 2 บวก b x y บวก c y ยกกำลัง 2 บวก d x บวก e y บวก f เท่ากับ 0	$\square^{\square}$	a ยกกำลัง x
$\square^{\square+\square}$	e ยกกำลัง x บวก y	$\square^{\square}+\square$	e ยกกำลัง x จบยกกำลัง บวก y

Appendix D Algebra (Cont.).

The letters are used with the symbol for clarify the expressions

Notations	Thai	Notations	Thai
$\square^{\square}\square^{\square}$	e ยกกำลัง x จบยกกำลัง e ยกกำลัง y	$\square^{\square\square^{\square}}$	e ยกกำลัง x a ยกกำลัง y จบยกกำลัง
$\square^{\square}\square$	e ยกกำลัง x จบยกกำลัง y	$\square^{\square 2\square\square}$	e ยกกำลัง I 2 π x จบยกกำลัง e ยกกำลัง y
$\log_{\square}\square$	ล็อก ของ a ฐาน b	$\log_{10} 3 \cdot 4$	ล็อก ของ 3 ฐาน b
$\log_{\square}\frac{2}{5}$	ล็อก ของ เศษ 2 ส่วน 5 ฐาน b	$\ln\square$	เนชั่วนอล ล็อก ของ x
$\square_1 + \square_2 + \cdots + \square_{\square}$	- a 1 บวก a 2 บวก ไปเรื่อยเรื่อย บวก a n - a ห้อย 1 บวก a ห้อย 2 บวก ไปเรื่อยเรื่อย บวก a ห้อย n	$\square_1 \cdot \square_2 \cdot \cdots \cdot \square_{\square}$	- a 1 ดอท a 2 ดอท ไปเรื่อยเรื่อย ดอท a n - a ห้อย 1 ดอท a ห้อย 2 ดอท ไปเรื่อยเรื่อย ดอท a ห้อย n
$\square_1 \cdot \square_1 + \square_2 \cdot \square_2 + \cdots + \square_{\square} \cdot \square_{\square}$	- a 1 ดอท b 1 บวก a 2 ดอท b 2 บวก ไปเรื่อยเรื่อย บวก a n ดอท b n - a ห้อย 1 ดอท b ห้อย 1 บวก a ห้อย 2 ดอท b ห้อย 2 บวก ไปเรื่อยเรื่อย บวก a ห้อย n ดอท b ห้อย n	$\square(\square) = \square_0\square^{\square} + \square_1\square^{\square-1} + \cdots + \square_{\square-1}\square + \square_{\square}$	- p ของ x เท่ากับ a 0 x ยกกำลัง n บวก a 1 x ยกกำลัง n ลบ 1 บวก ไปเรื่อยเรื่อย บวก a n ลบ 1 x บวก a n - p ของ x เท่ากับ a ห้อย 0 x ยกกำลัง n บวก a ห้อย 1 x ยกกำลัง n ลบ 1 บวก ไปเรื่อยเรื่อย บวก a ห้อย n ลบ 1 x บวก a ห้อย n
a|b	a หาร b ลงตัว	f(x)	f ของ x

Appendix E Trigonometric and Hyperbolic expressions.

The letters are used with the symbol for clarify the expressions

Notations	Thai	Notations	Thai
$\sin$ □	ซายน์ ของ x	$\cos$ □	คอส ของ x
$\tan$ □	แทน ของ x	$\cot$ □	ข็อท ของ x
$\sec$ □	เส็ก ของ x	$\csc$ □ cosec □	โคเส็ก ของ x
$\sin^2$ □	ซายน์ ยกกำลัง 2 ของ x	$\cos^2$ □	คอส ยกกำลัง 2 ของ x
$\tan^2$ □	แทน ยกกำลัง 2 ของ x	$\cot^2$ □	ข็อท ยกกำลัง 2 ของ x
$\sec^2$ □	เส็ก ยกกำลัง 2 ของ x	$\csc^2$ □ cosec^2 □	โคเส็ก ยกกำลัง 2 ของ x
$\sinh$ □	ซายน์ h ของ x	$\cosh$ □	คอส h ของ x
$\tanh$ □	แทน h ของ x	$\coth$ □	ข็อท h ของ x
sech □	เส็ก h ของ x	csch □ cosech □	โคเส็ก h ของ x
$\sin^{-1}$ □ arc sin □	- ซายน์ ยกกำลัง ลบ 1 ของ x - อาร์ค ซายน์ ของ x - ซายน์ อินเวิร์ส ของ x	$\cos^{-1}$ □ arc cos □	- คอส ยกกำลัง ลบ 1 ของ x - อาร์ค คอส ของ x - คอส อินเวิร์ส ของ x
$\tan^{-1}$ □ arc tan □	- แทน ยกกำลัง ลบ 1 ของ x - อาร์ค แทน ของ x - แทน อินเวิร์ส ของ x	$\cot^{-1}$ □ arc cot □	- ข็อท ยกกำลัง ลบ 1 ของ x - อาร์ค ข็อท ของ x - ข็อท อินเวิร์ส ของ x
$\sec^{-1}$ □ arc sec □	- เส็ก ยกกำลัง ลบ 1 ของ x - อาร์ค เส็ก ของ x - เส็ก อินเวิร์ส ของ x	$\csc^{-1}$ □ cosec^{-1} □ arc csc □ arc cosec □	- โคเส็ก ยกกำลัง ลบ 1 ของ x - อาร์ค โคเส็ก ของ x - โคเส็ก อินเวิร์ส ของ x
$\sinh^{-1}$ □ arc sinh □	- ซายน์ h ยกกำลัง ลบ 1 ของ x - อาร์ค ซายน์ h ของ x - ซายน์ อินเวิร์ส h ของ x	$\cosh^{-1}$ □ arc cosh □	- คอส h ยกกำลัง ลบ 1 ของ x - อาร์ค คอส h ของ x - คอส อินเวิร์ส h ของ x
$\tanh^{-1}$ □ arc tanh □	- แทน h ยกกำลัง ลบ 1 ของ x - อาร์ค แทน h ของ x - แทน อินเวิร์ส h ของ x	$\coth^{-1}$ □ arc coth □	- ข็อท h ยกกำลัง ลบ 1 ของ x - อาร์ค ข็อท h ของ x - ข็อท อินเวิร์ส h ของ x
sech^{-1} □ arc sech □	- เส็ก h ยกกำลัง ลบ 1 ของ x - อาร์ค เส็ก h ของ x - เส็ก อินเวิร์ส h ของ x	csch^{-1} □ cosech^{-1} □ arc csch □ arc cosech □	- โคเส็ก h ยกกำลัง ลบ 1 ของ x - อาร์ค โคเส็ก h ของ x - โคเส็ก อินเวิร์ส h ของ x

Appendix E Trigonometric and Hyperbolic expressions. (Cont.)

The following expression can be used for any of the six functions: sine, cosine, tangent, cotangent, secant, cosecant.

Notations	Thai	Notations	Thai
$\sin \square + \square$	ซายน์ ของ ทีต้า บวก x	$\sin(\square + \square)$	ซายน์ ของ วงเล็บเปิด ทีต้า บวก x วงเล็บปิด
$(\sin \square)\square$	ซายน์ ของ ทีต้า คูณ x	$\sin \square\square$	ซายน์ ของ ทีต้า x
$(\sin \square^2)\square$	ซายน์ ของ ทีต้า ยกกำลัง 2 จบยกกำลัง คูณ x	$\sin^2 \square \cos \square$	ซายน์ ยกกำลัง 2 ของ m ทีต้า คูณ คอส ของ ทีต้า
$\sin \square \cos \square$	ซายน์ ของ ทีต้า คูณ คอส ของ ทีต้า	$\sin(\square \cos \square)$	ซายน์ ของ วงเล็บเปิด ทีต้า คูณ คอส ของ ทีต้า วงเล็บปิด

Appendix F Logic and set theory.

Notations	Thai	Notations	Thai
$\sim p$	- น็อท p - นิเสธ p	$p \wedge q$	p และ q
$p \vee q$	p หรือ q	$p \rightarrow q$ $p \Rightarrow q$	ถ้า p แล้ว q
$p \leftrightarrow q$ $p \Leftrightarrow q$	p ก็ต่อเมื่อ q	$\forall x$	- ฟอร์ ออล x - สำหรับทุก ๆ x
$\exists x$	- ฟอร์ ซัม x - มี x บางตัว	$x \in A$	x เป็นสมาชิกของ A ใหญ่
$A \subset B$	A ใหญ่ เป็นสับเซตของ B ใหญ่	$A \subseteq B$	A ใหญ่ เป็นสับเซตของ หรือเท่ากับ B ใหญ่
$A \cap B$	A ใหญ่ อินเตอร์เส็ก B ใหญ่	$A \cup B$	A ใหญ่ ยูเนี่ยน B ใหญ่
$A - B$	A ใหญ่ ลบ B ใหญ่	A'	A ใหญ่ คอมพลีเมนท์
$A \cap (B \cup C)$	A ใหญ่ อินเตอร์เส็ก วงเล็บเปิด B ใหญ่ ยูเนี่ยน C ใหญ่ วงเล็บปิด	$A \cap B \cup C \cap D$	A ใหญ่ อินเตอร์เส็ก B ใหญ่ ยูเนี่ยน C ใหญ่ อินเตอร์เส็ก D ใหญ่
$A \cup (B \cap C)$	A ใหญ่ ยูเนี่ยน วงเล็บเปิด B ใหญ่ อินเตอร์เส็ก C ใหญ่ วงเล็บปิด	$(A \cup B)'$	คอมพลีเมนท์ ของ วงเล็บเปิด A ใหญ่ ยูเนี่ยน B ใหญ่ วงเล็บปิด
$A' \cap B'$	A ใหญ่ คอมพลีเมนท์ อินเตอร์เส็ก B ใหญ่ คอมพลีเมนท์	$B = \{1, 2, 3\}$	บี ใหญ่ เท่ากับ เซต ของ 1 2 และ 3
$A \times B = \{(1, 1), (1, 2), (1, 3)\}$	เอ ใหญ่ คูณ บี ใหญ่ เท่ากับ เซต ของ คู่อันดับ 1 1 คู่อันดับ 1 2 และ คู่อันดับ 1 3	$(x, y) \in f$	คู่อันดับ x y เป็น สมาชิก ของ f
$x \in \Re$	x เป็น สมาชิก ของ เซต ของ จำนวน จริง	(a, b)	ช่วงเปิด a b
$[a, b]$	ช่วงปิด a b	$(a, b]$	ช่วงครึ่งเปิด a b
$[a, b)$	ช่วงครึ่งปิด a b		

Appendix G Geometry.

Notations	Thai	Notations	Thai
(a, b)	- คู่อันดับ a b - จุด a b	P (a, b)	จุด P ใหญ่ ตำแหน่ง a b
(x, y, z)	- โคออดิเนต x y z - จุด x y z	$\overline{\square\square}$	ส่วนของเส้นตรง A ใหญ่ B ใหญ่
$\overrightarrow{\square\square}$	- รังสี A ใหญ่ B ใหญ่	$\overleftrightarrow{\square\square}$	- เส้นตรง A ใหญ่ B ใหญ่
$\overset{\frown}{AB}$	ส่วนโค้ง A ใหญ่ B ใหญ่		

Appendix H Calculus.

Notations	Thai	Notations	Thai
$\bar{x}$	x บาร์	(a, b)	- ช่วงเปิด a b - คู่อันดับ a b - จุด a b
[a, b]	ช่วงปิด a b	(a, b]	ช่วงครึ่งเปิด a b
[a, b)	ช่วงครึ่งปิด a b	$\sum_{i=1}^{n} x_i$	- ซัมเมชั่น ของ x i จาก i เท่ากับ 1 ถึง n - ผลบวกของ x i จาก i เท่ากับ 1 ถึง n
$\prod_{i=1}^{n} y_i$	ผลคูณ ของ y i จาก i เท่ากับ 1 ถึง n	$\lim_{x\to a} f(x) = L$	ลิมิต ของ f ของ x ที่ x เข้า ใกล้ a เท่ากับ L ใหญ่
$\lim_{x\to a^+} f(x)$	ลิมิต ของ f ของ x ที่ x เข้า ใกล้ a ทางบวก	$\lim_{x\to a^-} f(x)$	ลิมิต ของ f ของ x ที่ x เข้า ใกล้ a ทางลบ
$x \to 2^+$	x เข้าใกล้ 2 ทางบวก	$x \to 2^-$	x เข้าใกล้ 2 ทาง ลบ
$x \to \infty$	x เข้าใกล้ อินฟินิตี้	$f(x) \cdot g(x)$	f ของ x คูณ g ของ x
$f(g(x))$	f ของ g ของ x	$(f \circ g)(x)$	f o g ของ x
$f(x) = \begin{cases} 2 - x; x > 2 \\ 2; x = 2 \\ 2 + x; x < 2 \end{cases}$	f ของ x เท่ากับ 2 ลบ x เมื่อ x มากกว่า 2 เท่ากับ 2 เมื่อ x เท่ากับ 2 และ เท่ากับ 2 บวก x เมื่อ x น้อยกว่า 2	$dx = \Delta x$	d x เท่ากับ เดลต้า x
$f(x + \Delta x) \approx f'(x)dx + f(x)$	f ของ x บวก เดลต้า x ประมาณ f พราม ของ x d x บวก f ของ x	$\frac{df(x)}{dx}$	d f ของ x บาย d x
y'	y พราม	y''	y ดับ เบิล พราม
y'''	y ทริบ เบิล พราม	$y^{(n)}$	- y ดิฟ เฟอร์ เรน ชิ เอท ครั้งที่ n - y ยกกำลัง ในวงเล็บ n
$\frac{dy}{dx}$	d y บาย d x	$\frac{d^n y}{dx^n}$	d ยกกำลัง n y บาย d x ยกกำลัง n
$\frac{d}{dx}(u + v)$	d บาย d x ของ วงเล็บ เปิด u บวก v วงเล็บปิด	$f'(x)$	f พราม ของ x
$f'(g(x))$	f พราม ของ g ของ x	$f(g(x))'$	f ของ g ของ x พราม
$f'(g(x))g'(x)$	f พราม ของ g ของ x คูณ g พราม ของ x	$(f(x)g(x))'$	f ของ x คูณ g ของ x ทั้งหมด พราม
$f'(x)g(x) + f(x)g'(x)$	f พราม ของ x คูณ g ของ x บวก f ของ x คูณ g ของ x พราม	$\left(\frac{f(x)}{g(x)}\right)'$	เศษ f ของ x ส่วน g ของ x ทั้งหมด พราม

Appendix H Calculus. (Cont.)

Notations	Thai	Notations	Thai
$\frac{f'(x)g(x) + f(x)g'(x)}{g^2(x)}$	เศษ f พราม ของ x คูณ g ของ x บวก f ของ x คูณ g ของ x พราม ทั้งหมด ส่วน g ยกกำลัง 2 ของ x	|a|	แอบ ซา ลูซ ของ a
$\vec{u}$	เวกเตอร์ u	$\int f(x)dx$	อินทีเกรต ของ f ของ x d x
$\int_a^b f(x)dx$	อินทีเกรต ของ f ของ x d x จาก a ถึง b	$\int \frac{du}{u} = \ln\|u\| + c$	อินทีเกรต ของ เศษ d u ส่วน u เท่ากับ เนชัวนอ ลล็อก ของ แอบ ซา ลูท ของ u บวก c
$\left[2x - \frac{2x^3}{3}\right]_{-2}^{-1}$	วงเล็บเปิด 2x ลบ เศษ 2 x ยกกำลัง 3 ทั้งหมด ส่วน 3 วงเล็บปิด จาก -2 ถึง -1	$\pi[f(x)]^2$	พาย วงเล็บเปิด f ของ x วงเล็บปิด ทั้งหมด ยก กำลัง 2

Appendix I Linear algebra.

Notations	Thai	Notations	Thai
$\begin{bmatrix} 2 & 7 \\ 3 & 10 \end{bmatrix}$	- แมททริก 2 คูณ 2 แถวที่ 1 2 7 แถวที่ 2 3 10 - แมททริก 2 คูณ 2 คอลัมที่ 1 2 7 คอลัมที่ 2 3 10	$\begin{bmatrix} □_{11} & □_{12} & \cdots & □_{1□} \\ □_{21} & □_{22} & \cdots & □_{2□} \\ \cdots & & & \\ □_{□1} & □_{□2} & \cdots & □_{□□} \end{bmatrix}$	- แมททริก m คูณ n แถวที่ 1 a 1 1 a 1 2 จนถึง a 1 n แถวที่ 2 a 2 1 a 2 2 จนถึง a 2 n จนถึง แถวที่ m a m 1 a m 2 จนถึง a m n
$□_{□□}$	- a i j - a ห้อย i j	$□_{□+1,□}$	- a ซับสคริป 2 ตัว i บวก 1 และ j
det A	- เด็ทของ A ใหญ่ - ดีเทอร์มิแนนท์ของ A ใหญ่		

<u>เอกสารแนบหมายเลข 3</u>

Output จากโครงการวิจัยที่ได้รับทุนจาก สกว.

1. ผลงานตีพิมพ์ในวารสารวิชาการนานาชาติ (ระบุชื่อผู้แต่ง ชื่อเรื่อง ชื่อวารสาร ปี เล่มที่ เลขที่ และหน้า) หรือผลงานตามที่คาดไว้ในสัญญาโครงการ

   ระบุชื่อผู้แต่ง : ไม่มี
   ชื่อเรื่อง : ไม่มี
   ชื่อวารสาร : ไม่มี
   ปี : ไม่มี
   เล่มที่ เลขที่ : ไม่มี
   หน้า : ไม่มี

   กำลังเตรียม Manuscript เพื่อตีพิมพ์

   ระบุชื่อผู้แต่ง : **Wongkia, W.**, Chaowicharat, E.
   ชื่อเรื่อง : Automatic Thai Mathematical Speech Recognition
   ชื่อวารสาร : Computers and Mathematics with Applications
   ปี : -
   เล่มที่ เลขที่ : -
   หน้า : -

2. การนำผลงานวิจัยไปใช้ประโยชน์

   เชิงพาณิชย์ : ไม่มี
   เชิงนโยบาย : ไม่มี
   เชิงสาธารณะ : ไม่มี
   เชิงวิชาการ : ความรู้ที่ได้จากงานวิจัยนี้ถูกนำไปอ้างอิงในวารสารระดับนานาชาติ

3. อื่นๆ (เช่น ผลงานตีพิมพ์ในวารสารวิชาการในประเทศ การเสนอผลงานในที่ประชุมวิชาการ หนังสือ การจดสิทธิบัตร)

   -- ไม่มี --