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i-Math: Automatic math reader for Thai blind and visually impaired students[☆]

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ABSTRACT

We propose an automatic math expression reading system, called i-Math. i-Math is an educational tool, for blind and visually impaired (VI) students, to facilitate access to math materials. Although blind and VI students can access math documents/materials via many channels, e.g., human reader, math Braille codes, and audio (talking) books, these channels have limited availability. i-Math was designed to be an automatic reading aided tool and also a math learning and teaching tool for both students and teachers. i-Math operated with screen reader produce voice output on a computer. i-Math can read math documents aloud. Students can enjoy their newfound ability to read and practice math anytime and anywhere with i-Math while teachers can prepare their classroom handouts, assignments and exercises in audio version conveniently.

The evaluation of i-Math was conducted with 78 blind and VI students and six teachers. The evaluation results indicate that math materials can be easily accessible to blind and VI students through i-Math and then, they can independently and comfortably study and practice their mathematics.

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1. Introduction

Learning mathematics is necessary for students at all levels. Solving math problems is an alternative practice suggested for developing mathematical skills. Unfortunately, blind and visually impaired (VI) students face the difficulties at the first step due to their limitations in writing and reading math formulas especially. Although a large number of math problems are available both in printed materials and digital documents, blind and VI students barely benefit from them. They lose opportunities to practice on their own that will finally result in losing opportunities to develop their math skills.

Generally, blind and VI students can access materials/documents of math courses with the help of human readers; however, having human readers at their side at all times is impractical because of the cost and the limited availability of the trained personnel. Braille is the more convenient way for blind and VI students to access the documents. Unfortunately, not many documents are available in Braille since the production of math documents in Braille is rather difficult and complicated [1]. Moreover, most blind and VI students found that reading Braille math code is quite tedious and ambiguous due to the additional meanings of the cells, even for some who are comfortable reading literary Braille transcriptions. The sound-based representation represents an important channel to access information for the blind and VI students. DAISY books and talking books, for example, are the alternative audio materials that teachers can provide for the students; however,

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these books are less prepared for math and scientific expressions. With a hearing channel, a text-to-speech (TTS) engine has been widely used by blind and VI students to read electronic text through computers. A TTS engine is a system that can convert digital text into synthetic speech. Presently, TTS have recently become more suitable to individual needs. Screen reader and TTS technologies have made it possible to build reading aid devices for blind and VI readers. Unfortunately, most available TTS systems can read only plain text. They cannot be any assistance when it comes to math and scientific e-books, i.e., physics, chemistry, engineering which are full of equations and formulas with math symbols.

Many researchers realized that enhancing the accessibility to the math materials for blind and VI students was very important. They, therefore, attempted to develop TTS based systems to read math expressions, e.g., A_ST_ER, MathTalk, and MathPlayer in English [2–4]; AudioMath in Portuguese [5]; and Math Genie in English, French, and German [6,7]. A_ST_ER, MathPlayer and Math Genie add extra words or phrases to read math expressions. For example, the expression "$I = \int_0^\infty e^{-x}dx$" is read "*i* equals *x where x is the integral…*" or "*i* equals *limit*-integral with lower-limit zero and upper-limit infinity *expression something dx*. *Something is…*". The italic words and phrases are added to complete the reading. The rendered audio is very long and listeners may not be able to catch the main point of the expression if they listen for a long continuous period. The prosody, e.g., pitch change and duration, was introduced in MathTalk and AudioMath to convey the meaning of the expressions. However, the pitch change alone does not help in clarifying the meaning of the math expression in Thai since Thai language is a tonal language. Each syllable has a choice between five distinct tones: low, mid, rise, high and falling. Different tones result in different words with different meanings. For example, the five different tones /see/, /sèe/, /sêe/, /sée/ and /sĕe/ correspond to an English alphabet 'c', a number '4', a classifier[1] of 'rib or tooth', a verb 'die' and a noun 'color' respectively.

Moreover, these automatic math reader systems take inputs prepared in Latex or some markup languages. Unfortunately most Thai teachers, blind and VI students found that these document preparation systems are not easy to use, unlike Microsoft Word. Some systems scope their capabilities for algebraic expressions and some cover only math expressions appearing at the secondary school level in Thailand. We concentrated on secondary mathematics and extended to several topics at the high-school level including sequences and series, exponential and logarithm functions, and vectors.

Some systems presented output in both audio and Braille e.g., TRIANGLE, REMathEx and LAMBDA [9–11]. Also, the multimodality accessibility of math expressions was proposed to support individual preferences. This multimodality provided output in audio, tactile and visual forms [12,13] to support all desires of blind and VI people. However, the tool which provides only one form of output received more attention from the researchers because it is easier to develop and maintain.

In Thailand, TTS has gained the researchers' interest since 1980. A number of TTS systems, for example, CU-TTS [14], VAJA [15], PPA Tatip [16], and a stochastic knowledge-based Thai TTS system [17] were developed. These systems are able to synthesize Thai speech from Thai plain text only, not from math expressions however.

We are aware of the need of technologies that enable Thai blind and VI students to have the same opportunities as the sight students in studying, especially when studying mathematics and science. Therefore, we designed i-Math (an intelligent accessible mathematics system) with the capability to automatically convert both text and math expression into unambiguous speech as it is displayed on the screen. i-Math is a practical tool that enables blind and VI students to independently and comfortably study, practice mathematics and science anytime, anywhere.

To synthesize correct Thai speech for math expressions, a number of issues must be concerned. One important issue is that the same speech can lead to different expressions. For example, the speech

"*a* plus *b* over *c*"

could be transcribed into either

$$a + \frac{b}{c} \quad \text{or} \quad \frac{a+b}{c},$$

two different expressions which carries different meanings. Thus, the synthesizing algorithm should be carefully designed to generate an unambiguous speech which corresponds to exactly one expression. In doing so, we analyze the relationships between notations appearing in the expressions, their locations and the order of appearances of characters to determine whether and which extra words are required to convey the meaning of the expression.

This article is organized as follows. We discuss math expressions and Thai in Section 2. In Section 3, the architecture of i-Math is described. In Section 4, the roles of i-Math in educational environment are discussed. Section 5 contains the i-Math evaluation and results including performance of i-Math and the use of i-Math in education. In Section 6, we provide a summary and some general concluding remarks.

2. Differences between Thai and math expressions

Converting math expressions into speech is different from converting plain text due to the differences in alphabets/symbols and structures used. Also, the location where alphabets appear is significant since it indicates an audio

[1] In Thai, classifier is used to express a quantity of a countable noun; different nouns require different classifiers [8].

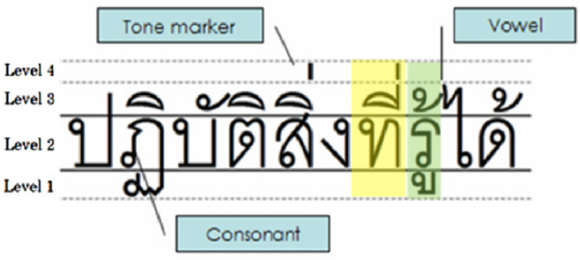

Fig. 1. Four levels of Thai characters.

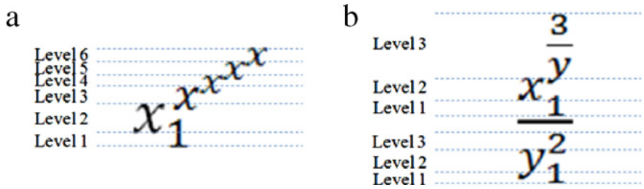

Fig. 2. A multi-level of math expressions.

$$\sum_{i=1}^{n} i^2 + 2i - 3 \qquad \lim_{x \to 0} \sum_{i=1}^{10} \frac{i - \sqrt{2}}{i + \sqrt{2}}$$

Fig. 3. Examples of special symbols in math expressions.

form of the alphabets. The differences between Thai plain text and math expression are discussed in this section. Math expression differs from Thai plain text in alphabets/symbols, writing and reading systems as listed below:

- *Alphabets and symbols*: Thai alphabet system contains 44 consonants (e.g., ก, ฎ, ป, ฌ, ญ), fifteen vowels (e.g., อุ,[2] อา, อี, โอ), and four tone markers (e.g., อ่, อ้, อ๊, อ๋) while math expressions uses normal English letters in upper case and lower case (e.g., a, b, A, B), digits (e.g., 0, 1, 2, 3); Greek letters (e.g., α, δ, ε, θ, π) and math symbols (e.g., $+$, $-$, $\div$, $<$, $=$).
- *Display*: Thai text and math expressions are written in non-linear form. Thai text is written in four levels. The word "ที่ (/têe/, that, at, place)[3]" shown in Fig. 1 presents in three levels. Three alphabets, an initial consonant "ท", a vowel "อี" and a tone marker "อ่" appear in level 2, 3 and 4 respectively. Another word "รู้ (/róo/, know)" is composed of three alphabet symbols as well, an initial consonant "ร", a vowel "ู" and a tone marker "อ้", appearing in levels 2, 1 and 3 respectively.

  Unlike Thai text, a math expression is a multi-level system as shown in Fig. 2. In Fig. 2(a), x_1 to the power of $x^{x^{x^x}}$ appears in six levels. Fig. 2(b) illustrates a fraction where the numerator appears in three levels and the denominator in three levels as well.

Special math symbols are a group of symbols including a vinculum or a fraction bar "—", a summation operator "$\sum$", a product operator "$\prod$", an integration sign "$\int$", a limit notation "lim" and a root sign "$\sqrt{}$". Some examples are shown in Fig. 3.

- *Location and order*: The location and order of appearances of characters determines whether and which extra words are required to convey the meaning of the expression. Table 1 illustrates locations of "3" and "x" in eight different expressions.

To correctly read these expressions, different extra words are required in different expressions. No extra word is needed in the first expression. In 2nd row, the word "คูณ (/koon/, multiply)" may or may not be added into the reading, it does not affect the meaning of the expression. The word "ยกกำลัง (/yók-gam-lang/, to the power of)" is required in reading the 3rd expression. The word "เศษ" and "ส่วน" are added to identify the numerator and denominator of the fraction in the 5th expression. The word "ทั้งหมด (/táng-mòt/, all)" is added to indicate the expression boundary. In the 6th expression, the word "ทั้งหมด (/táng-mòt/, all)" is added to indicate that the 3rd power is for "$x + y$". A logarithm is written in a subscript form, $\log_3 x$, composing the base 3 and the expression x in the last row. The word "ล็อก (/lók/, log)" is the transliteration of "log" while the word "ฐาน (/tăan /, base)" refer to "to base". And, the word "ของ (/kŏng/, of)" is pronounced before the expression x.

[2] A consonant position is indicated by o.

[3] In the parenthesis follows Thai words, the first is its pronunciation, the next are all possible meanings.

Table 1
The location of “3” and “x” in six different expressions.

Expression	Thai	Pronunciation	Description
x_3	เอ็กซ์ สาม	/èk săam/	The third term of x
$3x$	สาม คูณ เอ็กซ์ or สาม เอ็กซ์	/săam koon èk/ or /săam èk/	Three times x
x^3	เอ็กซ์ ยกกำลัง สาม	/èk yók-gam-lang săam/	The third power of x
$\sqrt[3]{x}$	รากที่ สาม ของ เอ็กซ์	/râak-têe săam kŏng èk/	The third root of a x
$\frac{x}{3}$	เศษ เอ็กซ์ ส่วน สาม	/sàyt èk sùan săam/	x divided by three
$\frac{3}{x}$	เศษ สาม ส่วน เอ็กซ์	/sàyt săam sùan èk/	Three divided by x
$(x + y)^3$	เอ็กซ์ บวก วาย ทั้งหมด ยกกำลัง สาม	/èk bùak waai táng-mòt yók-gam-lang săam/	x plus y all to the power of three
$\log_3 x$	ล็อก ฐาน สาม ของ เอ็กซ์	/lók tăan săam kŏng èk/	Log x to base three

- *Characters-Thai sound mapping*: A single character in a math expression can be mapped to one or more sounds, e.g., “π” is mapped to one sound /paai/ while the notation “$<$” is mapped to two sounds /nói-gwàa/. But in the opposite, one sound in Thai text can correspond to two or more alphabets, e.g., “มาก” a three-alphabet symbol is mapped to one sound /mâak/ while “รถ” a two-alphabet symbol is mapped to one sound /rót/.
- *Homograph*: The correct pronunciation of a Thai homograph depends on its context. For example the word “สระ” can be pronounced as “(/sà-rà/, vowel)” or “(/sà/, pool)”. There is a kind of *homograph* in mathematics as well. The correct reading of a math expression depends on where it appears. For example, “1–12” either refers to “one to twelve /nèung tĕung sìp-sŏng/” or “one minus twelve /nèung lóp sìp-sŏng/”.

The dot “.” that comes after the number “7.” is not a part of the math expression. It is read “item seven /kôr jèt/” while the dot “.” that lies between two number “12.5” indicates that “12.5” is a decimal number so it is read “twelve point five/ sìp-sŏng jùt hâa/”. Furthermore, the dot that comes after “ซม.” (cm: centimeter) is left unsounded, it is a part of the abbreviation.

One surface form of a math expression carries only one meaning (in mathematics). For example, if we see the expression

$$\frac{a+b}{b+c},$$

we will read it as “a plus b over b plus c”. However, if we heard such expression, we could interpret it as either

$$\frac{a+b}{b+c} \quad \text{or} \quad \frac{a+b}{b}+c.$$

3. Design of i-Math

Two aspects were concerned in designing i-Math. First, most materials in mathematics (e.g., exercises or math textbooks) are available in electronic form. Second, i-Math must generate an accurate speech output. Thus the design of i-Math performs speech generation in four modules: XML Conversion module, MathEx Structure Analysis module, Math–Thai Mapping module and Speech Synthesis module (Fig. 4).

The input of i-Math is math text containing both Thai text (Thai) and math expressions (MathEx). To support Microsoft Word (MS Word), the XML conversion module converts a MS Word document into a corresponding eXtensible Markup Language (XML) document. To retain complete meaning, the MathEx Structure Analysis module adds necessary words required in reading math expressions by analyzing several math expressions. To provide clear and correct pronunciation, the Math–Thai Mapping module replaces all foreign alphabets with their Thai pronunciation patterns and the Speech synthesis module generates corresponding Thai speech for all Thai pronunciation patterns.

3.1. XML conversion

Math expressions are used to communicate math concepts between people. Two-dimensional math expressions are widely used by hand writing with a pencil and paper (Fig. 5(a)). Currently, most popular text editor, MS Word, allow users to create math expressions with an equation editor option (Fig. 5(b)).

An alternative system used to represent math expressions is the TEX or LATEX system that is a one-dimensional math expression. An example of LATEX representation for the expression in Fig. 5 is shown below:

```
\[x = \frac{−b \pm \sqrt{bˆ{2} − 4ac}}{2a}\]
```

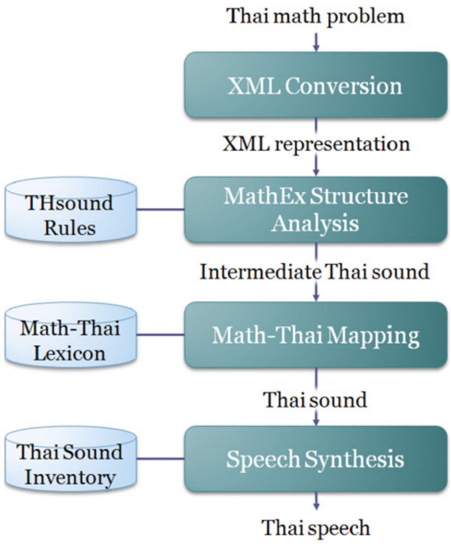

Fig. 4. i-Math architecture.

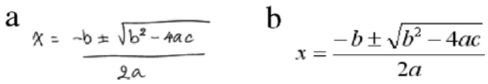

Fig. 5. A two-dimensional math expression (a) a hand written and (b) an equation editor.

```
1  <m:oMath>
2      <m:f>
3          <m:num>
4              <m:r>
5                  <m:t>a</m:t>
6              </m:r>
7          </m:num>
8          <m:den>
9              <m:r>
10                 <m:t>b</m:t>
11             </m:r>
12         </m:den>
13     </m:f>
14 </m:oMath>
```

Fig. 6. An example XML representation for the fraction $\frac{a}{b}$.

With the popularity of the World Wide Web (WWW), the World Wide Web Consortium (W3C) has recently introduced XML technology [18]. XML is used for representation, manipulation and exchange of structure information including math expressions illustrated in Fig. 6.

The <m:oMath>, <m:f>, <m:num>, and many more are tags of XML [19] which is written between angle brackets. XML tags open with the "<" symbol and end with the ">" symbol. For example (in line 5), <m:t> is an starting tag. All starting tags must have ending tags, in this case the ending tag is </m:t>. The text between the starting and ending tags is element content which is data of the document, in this case the element content is a and b in line 5 and 10, respectively.

The first module, XML Conversion, converts an input document into a corresponding XML document. An input document is in a MS Word format file version 2007 (or higher) since this word processor is widely used and most Thai teachers, blind and VI students are familiar with it. In addition, MS Word document can simply be converted into XML document. Unlike other input format such as LaTeX, most Thai teachers and students are difficult in document preparation and use. In this article, the document containing math word problems exercises are used as input examples. Fig. 7 presents the word problem example together with its XML representation. In XML representation, Thai and math expression (MathEx) are clearly separated with tags, e.g., <w:body>, <w:r> and <m:oMath>.

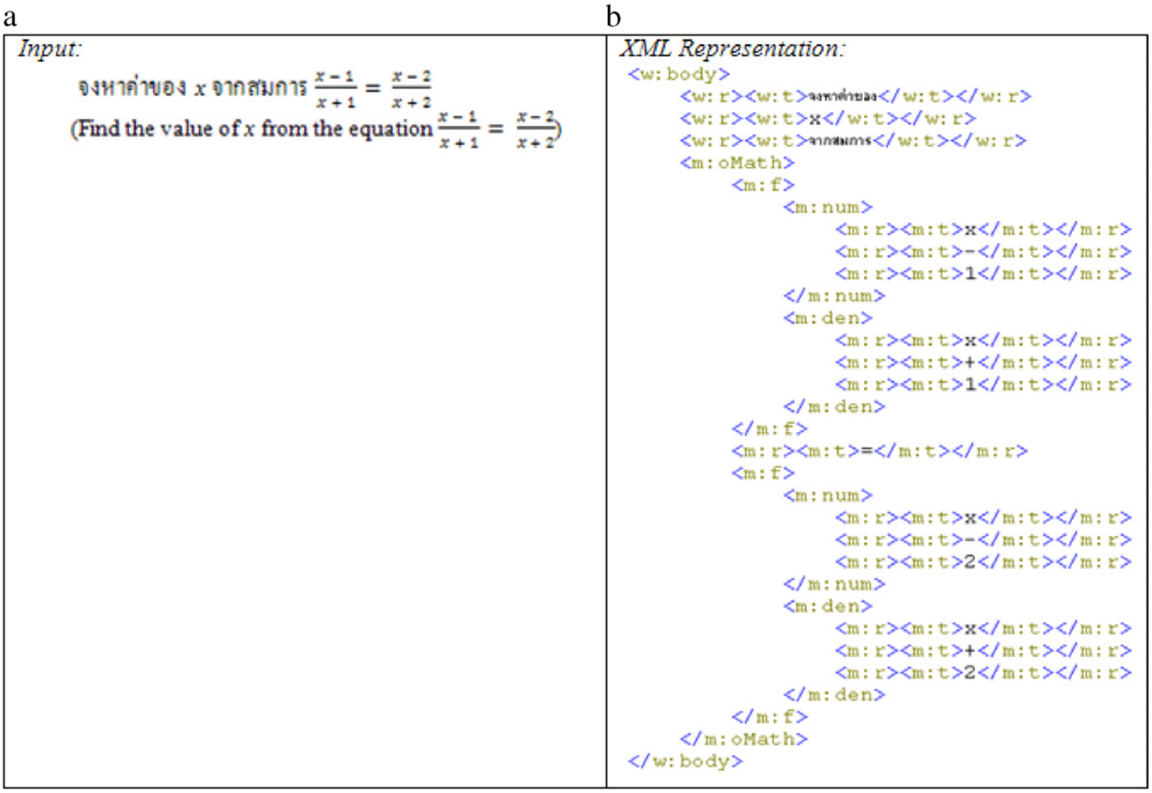

Fig. 7. An example of a Thai math text (a) and its converted XML representation (b).

3.2. MathEx structure analysis

In reading a math expression, unlike reading Thai plain text, some particular words that do not appear in the expression are uttered to clarify the meaning of the input expression. In doing so, some Thai words (THsound) are required to convey the meaning of an original math expression. We therefore analyzed each math expression structure to develop the rules based on the syntax and semantics of math expressions. These particular words are referred to as THsounds in this article.

To accurately read the math expressions in Thai, each structure of expressions needs to be analyzed. The different expressions need the different Thai words and the rules to complete the accurate reading. We consider several math expressions which include basics (e.g. decimals, $3x + 3y = 12$, and $5 \times 9 \div 3 \neq 10$), fractions, powers, and radicals.

In an example, to correctly read fractions in Thai, a numerator is read first by beginning with the word "เศษ (/sàyt/, numerator)". Then, a denominator is followed by the word "ส่วน (/sùan/, denominator)". The expression,

$$\frac{a}{b}$$

is uttered "เศษ *a* ส่วน *b*". To identify the end of the numerator, the word "ทั้งหมด (/táng-mòt/, all)" is read when the numerator is not one character. The expression,

$$\frac{a+b}{c}$$

is read as "<u>เศษ</u> *a* บวก *b* <u>ทั้งหมด</u> <u>ส่วน</u> *c*". The three underline words "เศษ", "ทั้งหมด" and "ส่วน" are added into the utterance to identify the beginning of the numerator, the end of the numerator and the beginning of the denominator respectively. The word "ทั้งหมด" is added to read this expression because the numerator is comprised of three characters, '*a*', '+' and '*b*'. The expression,

$$\frac{a+b}{c} + d$$

is uttered "<u>เศษ</u> *a* บวก *b* <u>ทั้งหมด</u> <u>ส่วน</u> *c* **ทั้งหมด** บวก *d*" that means "*a* plus *b* all over *c* **all** plus *d*". The boldface word "ทั้งหมด (/táng-mòt/, all)" is added to identify the end of a fraction. Some examples of the Thai pronunciations for fractions show below:

$\frac{a}{b}$	เศษ a ส่วน b	sàyt ay sùan bee	a over b
$\frac{a}{b+c}$	เศษ a ส่วน $b + c$	sàyt ay sùan bee bùak see	a over $b + c$
$\frac{a+b}{c}$	เศษ $a + b$ ทั้งหมด ส่วน c	sàyt ay bùak bee táng-mòt sùan see	$a + b$ all over c
$\frac{a}{b^2}$	เศษ a ส่วน b ยกกำลัง 2	sàyt ay sùan bee yók-gam-lang sŏng	a over b squared
$a + \frac{b}{c}$	a + เศษ b ส่วน c	ay bùak sàyt bee sùan see	a plus b over c
$\frac{a+b}{b+c}$	เศษ $a + b$ ทั้งหมด ส่วน $b + c$	sàyt ay bùak bee táng-mòt sùan bee bùak see	a plus b all over b plus c
$\frac{\frac{a}{x}}{\frac{b}{y}}$	เศษ เศษ a ส่วน x ทั้งหมด ส่วน เศษ b ส่วน y	sàyt sàyt ay sùan èk táng-mòt sùan sàyt bee sùan waai	a over x all over b over y
$\frac{a^2}{b}$	เศษ a ยกกำลัง 2 ทั้งหมด ส่วน b	sàyt ay yók-gam-lang sŏng bee táng-mòt sùan bee	a squared all over b
$\frac{a+b}{c}+d$	เศษ $a + b$ ทั้งหมด ส่วน c ทั้งหมด $+ d$	sàyt ay bùak bee táng-mòt sùan see táng-mòt bùak dee	$a + b$ all over c all plus d

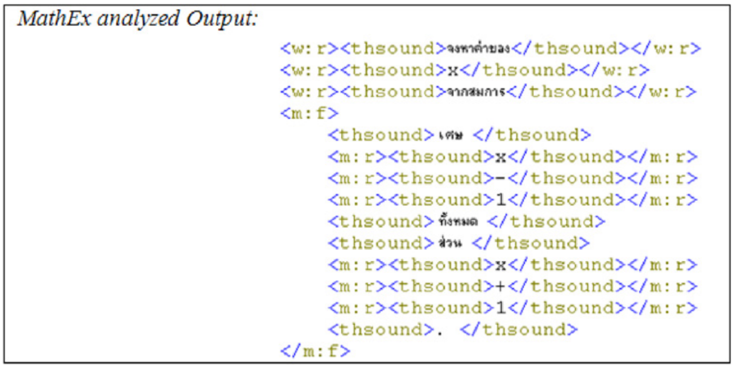

Fig. 8. An example of corresponding THsound for a fraction.

MathEx Structure Analysis, the second module, analyzes the XML representation to determine which words should be added and where they should be placed to correctly retain the meaning of the input expression. The analysis is done using eXtensible Stylesheet Language Transformations (XSLT) by [20]. Fig. 8 presents the analyzed output of the previous example.

3.3. Math–Thai mapping

In the third module, Math–Thai Mapping, each math element is mapped into its corresponding Thai sound. Fig. 9 illustrates the mapping output of the previous example, an English alphabet 'x' and an operator '—' are mapped into "เอ็กซ์" and "ลบ".

3.4. Speech Synthesis

Speech Synthesis module, the last module generates Thai speech output for the input string. The knowledge-based system used in this module was developed based on stochastic knowledge-based Thai TTS system [17]. In our knowledge-based system, the sound unit was categorized into initial demisyllables, final demisyllables, consonant–vowel diphones, syllables with some plosive sound and syllables borrowed from a foreign language for forming a natural Thai speech. Moreover, the most widely used TD-PSOLA model [21] is employed to select smooth concatenation and provide good control of pitch and duration. Fig. 10 presents the utterance words of the input.

4. i-Math: an educational tool

There are a number of possibilities of using i-Math to provide the blind and VI students an equal opportunity for studying both inside and outside of the classroom. Some possibilities are discussed below.

Mapping Output:

```
<w:r><thsound>จงหาค่าของ</thsound></w:r>
<w:r><thsound>เอ็กซ์</thsound></w:r>
<w:r><thsound>จากสมการ</thsound></w:r>
<m:f>
    <thsound> เศษ </thsound>
    <m:r><thsound>เอ็กซ์</thsound></m:r>
    <m:r><thsound>ลบ</thsound></m:r>
    <m:r><thsound>1</thsound></m:r>
    <thsound> ทั้งหมด </thsound>
    <thsound> ส่วน </thsound>
    <m:r><thsound>เอ็กซ์</thsound></m:r>
    <m:r><thsound>บวก</thsound></m:r>
    <m:r><thsound>1</thsound></m:r>
    <thsound>. </thsound>
</m:f>
```

Fig. 9. An example of mapping result.

Input:	*Speech Output:*
จงหาค่าของ x จากสมการ $\frac{x-1}{x+1} = \frac{x-2}{x+2}$ (Find the value of x from the equation $\frac{x-1}{x+1} = \frac{x-2}{x+2}$)	จงหาค่าของ เอ็กซ์ จากสมการ เศษ เอ็กซ์ ลบ 1 ทั้งหมด ส่วน เอ็กซ์ บวก 1 เท่ากับ เศษ เอ็กซ์ ลบ 2 ทั้งหมด ส่วน เอ็กซ์ บวก 2

Fig. 10. An example of speech result.

4.1. Math teacher and classroom

In classroom, the conventional print-based materials such as textbooks, handouts, activity sheets and tests present a barrier to blind and VI students. To overcome such a barrier, i-Math must be incorporated into the materials that are already in digital form. The digital materials augmented with i-Math allow students with different needs and learning styles to access the same materials equally. The following are examples of how teachers can utilize i-Math in their classrooms.

- Create the classroom handouts, assignment and exercises using MS Word so that the students can listen through i-Math.
- Look for the supplemental classroom materials on the Internet, download the files and convert them into "*.docx" files to be used in the classroom with i-Math.
- Request digital files of the textbooks purchased and then create an instant audio version of these textbooks simply and conveniently using i-Math.
- Have the students take tests via computer. Create the tests in digital form using MS Word students can then use i-Math to read the test at any speed according to their own needs.

The key benefit of using i-Math during classes is that it gives students a sense of independence and confidence that they do not have without use of this tool. The other benefit is that teachers and teaching assistants can focus on other weaknesses of a student or other students who might have a higher level of need, instead of having to read text to blind and VI students.

4.2. Blind and VI students at home

i-Math plays a vital role in making computers accessible as a tool to a student at home. It has opened up the possibilities for blind and VI students to study from the available materials and practice at their own pace at whatever time they choose. The students have no longer to wait for somebody to read to them. They can use i-Math in the following ways.

- Use i-Math to listen to the course materials, e.g., class notes, textbooks, and able to repeat the reading anytime they want.
- Create audio version from the course material or chosen materials for later use.
- Read the math problem exercises and practice on their own pace.
- Read the materials and resources available on the Internet (e.g., CAI, e-books, and intelligent tutoring system) and study using i-Math.
- Use i-Math to proofread the solutions or answers of the problems before turning them in, and correct any mistake if necessary.

With i-Math, students can enjoy their newfound ability to read anytime, anywhere. i-Math helps blind and VI to build independence text access on their own schedule.

Table 2
Examples of math test used in this evaluation.

No.	Math test
P001	จงหาค่าของ $24 \times 6 \div 3$ (Find the value of $24 \times 6 \div 3$.)
P022	จงหาค่าของ $2^2 + 3^2$ (Find the value of $2^2 + 3^2$)
P045	จงหาค่าของ $\sqrt{625} + \sqrt[4]{64}$ (Find the value of $\sqrt{625} + \sqrt[4]{64}$.)
P062	จงหาค่าของ x จากสมการ $\frac{x-1}{x+1} = \frac{x-2}{x+2}$ (Find the value of x from the equation $\frac{x-1}{x+1} = \frac{x-2}{x+2}$.)
P077	จงหาค่าของ x จากสมการ $\sqrt{x-2} = \sqrt{25}$ (Find the value of x from the equation $\sqrt{x-2} = \sqrt{25}$)
P096	กำหนดให้ $9^x = 3^{x+5}$ จงหาค่า x ที่ทำให้สมการเป็นจริง (Let $9^x = 3^{x+5}$, find the value of x that make this equation is true.)
P112	น้ำตาลทราย $5\frac{1}{4}$ กิโลกรัม แบ่งใส่ถุง ถุงละ $\frac{3}{4}$ กิโลกรัม จะแบ่งใส่ถุง ได้ทั้งหมดกี่ถุง (There are sugar weighted $5\frac{1}{4}$ kilograms, divided into bags each bag weighs $\frac{3}{4}$ kilograms. How many bags are there totally?)

5. Evaluation of i-Math

In this section, we first evaluate the performance of the i-Math in terms of whether it can produce an acceptable speech output. Then, we examine the use of i-Math in educational environment, the Mathematics classes of 7–9 grade level.

Six teachers (two males and four females) and 78 students from two secondary schools[4] in central part of Thailand participated in this study. Students are in 7–9 grade and range in age from 12 to 20 years old. 52 students are blind (17 males and 35 females) and 26 are visually impaired (nine males and 17 females).

In this study, all six teachers prepared handouts for their classes using MS Word incorporated with i-Math. The participated students studied these handouts at home after class. Teachers created homework and exercises using MS Word and allowed students to use i-Math in doing their homework and exercises both in class and at home. Students used i-Math in proofreading their homework before turning them in on the next day. During the test, the students were allowed to use i-Math in reading the test. They were able to read the test at their own speed, they could repeat the reading as often as they wanted. Examples of the test, math word problems, are illustrated in Table 2. Each problem contains both Thai text and math expressions. Their English translations are provided in parenthesis underneath.

5.1. Performance of i-Math

To examine whether i-Math can generate an acceptable speech output, we asked the students to carefully listen to i-Math and transcribe exactly what they have heard while studying their handouts, doing their homework, exercises and tests. Their handouts, homework and tests are available in Microsoft office word format. Some transcriptions of "P001" and "P096" by nine students presents in Fig. 11. The "Correct Speech" with the word number underneath is the speech we are expected from i-Math, there are 10 words and 21 words in P011 and P096 respectively. The expression in P001 is clear and uncomplicated, so most students could transcribe them into the same transcriptions. However, P096 is more complicated, the reading was transcribed into several transcriptions (see Fig. 12).

From students' transcriptions, three variables including percentage of missing words, percentage of incorrect words, and percentage of correct words were used to determine the performance of i-Math. Missing word refers to the word that a student did not transcribe, though the i-Math uttered the word. Incorrect word is the word that the student transcribed differently from what i-Math spoke. Correct word is the word that the student transcribed exactly the same word uttered by i-Math.

$$Percentage\ of\ missing\ words = \frac{Numbers\ of\ missing\ words}{Numbers\ of\ total\ words} \times 100 \tag{1}$$

$$Percentage\ of\ incorrect\ words = \frac{Numbers\ of\ incorrect\ words}{Numbers\ of\ total\ words} \times 100 \tag{2}$$

$$Percentage\ of\ accuracy\ words = \frac{Numbers\ of\ accuracy\ words}{Numbers\ of\ total\ words} \times 100. \tag{3}$$

4 There are approximately twenty schools for blind and VI across Thailand and 150 students in grade 7–9.

P001: จงหาค่าของ $24 \times 6 \div 3$
(Calculate $24 \times 6 \div 3$.)
Correct จง หา ค่า ของ ยี่สิบ สี่ คูณ หก หาร สาม
Speech: 1 2 3 4 5 6 7 8 9 10
Student1: จง หา ค่า ของ ยี่สิบ สี่ คูน หก หาน สาม
Student2: จง หา ค่า ของ ยี่สิบ สี่ คูน หก หาน สาม
Student3: จง หา ค่า ของ ยี่สิบ สี่ คูน หก หาน สาม
Student4: จง ห้า ค่า ของ ยี่สิบ ซี่ คูน หก หาน สาม
Student5: จง หา ค่า ของ $\frac{24 \times 6}{3}$
Student6: จง หา ค่า ของ ยี่สิบ สี่ คูน หก หาน สาม
Student7: จง หา ค่า ของ ยี่สิบ สี่ คูน หก หาน สาม
Student8: จง หา ค่า ของ ยี่สิบ สี่ คูน หก หาน สาม
Student9: จง หา ยี่สิบ สี่ คูน หก หาน สาม

P096: กำหนดให้ $9^x = 3^{x+5}$ จงหาค่า x ที่ทำให้สมการเป็นจริง
(Let $9^x = 3^{x+5}$, find the value of x that make this equation is true.)
Correct กำหนด ให้ เก้า ยกกำลัง เอ๊กซ์ เท่ากับ สาม ยกกำลัง เอ็กซ์ บวก ห้า จง หา ค่า เอ๊กซ์ ที่ ทำ ให้ สมการ เป็น จริง
Speech 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Student1: กำหนด ให้ เก้า ยกกำลัง หนึ่ง เท่ากับ สาม ยกกำลัง เอ บวก ห้า จง หา เอ
Student2: กำหนด ให้ เก้า ยกกำลัง เอะ เท่ากับ (สาม ยกกำลัง เอะ) บวก ห้า จง หา ค่า เอะ ที่ ทำ ให้ สมการ เป็น จะล่ม
Student3: เก้า ยกกำลัง เอะ เท่ากับ สาม ยกกำลัง เอะ จง หา ค่า ของ สมการ เป็น จะล่ม
Student4: กำหนด ให้ เก้า ยกกำลัง เอ เท่ากับ (สาม ยกกำลัง เอ) บวก ห้า จง หา ค่า เอ ที่ ทำ ให้ สมการ เป็น จริง
Student5: กำหนด ให้ $9^{11} = 3^{11} + 5$ ให้ สมการ เป็น จริง
Student6: กำหนด ให้ เก้า ยกกำลัง เอ เท่ากับ (สาม ยกกำลัง เอ) บวก ห้า จง หา ค่า เอ ที่ ทำ ให้ สมการ เป็น จริง
Student7: กำหนด ให้ เก่า ยกกำลัง ... จง หา ค่า ของ เอะ ของ สมการ
Student8: กำหนด ให้ เก้า ยกกำลัง หนึ่ง เท่ากับ สาม ยกกำลัง เก้า ทำ ให้ สมกาน ของ จะล่ม
Student9: เก้า ยกกำลัง เอ เท่ากับ (สาม ยกกำลัง เอ) บวก ห้า จง หา ค่า เอ ทำ ให้ สมการ เป็น จริง

Fig. 11. Examples of students' transcriptions.

P062

Generated speech: เศษ เอ็กซ์ ลบ หนึ่ง ทั้ง หมด ส่วน เอ็กซ์ บวก หนึ่ง เท่า กับ เศษ เอ็กซ์ ลบ สอง ทั้ง หมด ส่วน เอ็กซ์ บวก สอง

x minus one all over x plus one equal to x minus two all over x plus two.

Possible transcription 1: $\frac{x-1}{x+1} = \frac{x-2}{x+2}$

Possible transcription 2: $\frac{x-1}{x} + 1 = \frac{x-2}{x} - 2$

P096

Generated speech: เก้า ยก กำ ลัง เอ็กซ์ เท่า กับ สาม ยก กำ ลัง เอ็กซ์ บวก ห้า

Nine to the power of x equal to three to the power of x plus five.

Possible transcription 1: $9^x = 3^{x+5}$

Possible transcription 2: $9^x = 3^x + 5$

Fig. 12. Examples of two different transcriptions from the utterances in P062 and P096.

Descriptive statistics (mean and standard deviation) of the missing, incorrect and correct word of each transcription were calculated. Part of the calculations reported in Table 3. The missing words numbers of P062 and P096 are very high since the speech of math problems can lead to two different transcriptions (Fig. 12), therefore the students were uncertain what should be written.

Table 4 presents the descriptive statistics of the three variables of all 120 students' transcriptions. It indicates that i-Math is able to produce an acceptable speech output since the number of missing and incorrect words is low (6.26%, 4.67%) while the number of correct word is high (89.10%).

Table 3
Descriptive statistics of missing words, incorrect words and correct words of some transcriptions.

Variable	Mean (n[a] = 78)					Std.dev (n = 78)				
	P001	P045	P062	P096	P112	P001	P045	P062	P096	P112
Missing words (%)	**0.13**	3.69	28.08	**28.75**	7.10	**0.11**	1.29	6.46	**6.62**	1.54
Incorrect words (%)	**0.51**	2.00	4.82	**13.61**	2.61	**0.22**	0.83	1.25	**1.76**	1.11
Correct words (%)	**99.36**	94.31	72.55	**57.63**	89.25	**2.95**	9.57	25.63	**27.09**	7.66

[a] n = number of students.

Table 4
Descriptive statistics of missing words, incorrect words and correct words of 120 transcriptions.

Variable	Mean (m[a] = 120)	Std.dev (m = 120)
Missing words (%)	6.26	6.96
Incorrect words (%)	4.67	3.45
Correct words (%)	89.10	8.08

[a] m = number of transcriptions.

Table 5
Frequency table of some questionnaire items responded by teachers (n = 6).

Questions	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I would find that i-Math helped my students in reading math handouts, exercises and tests.	3	3	0	0	0
I would find that i-Math helped my students to pay more attentions in studying mathematics.	1	3	1	1	0
I would find that i-Math was helpful to use with the effective available math CAI.	0	4	2	0	0
I would find that i-Math could enhance the ability of my students in studying on their own.	1	3	2	0	0
I would find that i-Math was easy to use.	3	2	1	0	0
I am willing to use i-Math in my class.	5	0	1	0	0
I will recommend i-Math to others.	6	0	0	0	0

5.2. The use of i-Math in education

It was found that Technology Acceptance Model (TAM) by Davis [22] is one of the most information systems theories used to measure how users accept and use a technology when the users are presented with a new technology. Davis introduced perceived usefulness and perceived ease of use to indicate the users' beliefs. Perceived usefulness was defined as the degree to which a person believes that using a particular system would enhance his or her job performance while perceived ease of use referred to the degree to which a person believes that using a particular system would be free of effort.

To investigate the use of i-Math in educational environment, we asked the participants, teachers and students, to answer the questionnaire survey that was designed based on TAM. Our designed questionnaire was approved by four experts in mathematics, computer education, educational assessment and special education for disabilities. The Cronbach's alpha measurement (0.83) indicates that the designed questionnaire is reliable. The scale is rated from 1–5 (5—strongly agree, 4—agree, 3—neither, 2—disagree, 1—strongly disagree). Table 5 shows frequency calculated on some questionnaire items responded by teachers. It shows that the teachers had positive perception toward the use of i-Math. All teachers agreed that i-Math helped their students in reading math documents since i-Math allows a user to input math documents in widely available forms. Four teachers affirmed that i-Math helped their students to pay more attentions in studying mathematics. Most teachers will use i-Math in their classes and certainly recommend it to others. The following are some of their remarks.

"I do not know Braille for mathematics well so i-Math is good for me because I can prepare the math lessons easily."

"I can type all math expressions on a regular editor and my students can use i-Math to read them. My students can practice exercises on their own. However, it is new to me. If I have more time to work on this tool I should be able to make it do whatever I want to do easier."

Table 6 summarized the frequency calculated on some questionnaire items responded by students as percentages of the totals. It indicates that seventy-nine percent of the students agreed that i-Math helped them in reading math expressions. Sixty-six percent reported that i-Math reduced time consumed in doing their homework and exercises. The majority of the students found that i-Math is a usable tool and will recommend it to others. Some suggestions from the students for further improvement are following.

"I do not like mathematics, but i-Math is good for me. I felt comfortable when using i-Math to read math problems, it made distorted voice sometimes though. If i-Math can produce a better Thai pronunciation, it will be good for any blind people in learning mathematics".

Table 6
Frequency table of some questionnaire items responded by students ($n = 78$).

Questions	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
I would find that i-Math helped me to read math expressions.	21	58	16	5	0
I would find that i-Math reduced time consumed in practicing mathematics.	22	44	13	15	6
I would find that i-Math was easy to use.	27	44	10	18	1
I would find that i-Math helped me to pay more attention in studying.	29	27	30	14	0
I would find that i-Math was useful.	35	50	15	0	0
I am willing to use i-Math in studying mathematics.	36	24	28	12	0
I will recommend i-Math to my friends.	54	19	21	5	1

"It is difficult for me to try to remember what i-Math says and I felt a little bit uncomfortable using it. The system should allow me to pause or stop any time I want. However, I think i-Math is a very good system in helping me to learn mathematics."

"I am low vision. i-Math is an interesting system that can help my friends who are blind to learn mathematics. However, i-Math should produce the better pronunciations. For complicated math expressions, the system should allow us to pause, play and stop because I need more time to understand and take a note."

6. Concluding remarks

Blind and visually impaired (VI) students have difficulties in learning mathematics so do Thai blind and VI students. One alternative way to assist them is the text-to-speech (TTS) technologies with the capability to read math expressions out loud. However, none of available TTS can read math expressions in Thai. Therefore, we proposed i-Math, a tool to enable Thai blind and VI students independently and comfortably study and practice mathematics.

i-Math determines which and where extra words are needed by analyzing the structure of a math expression input in terms of both syntax and semantics to ensure a clear and concise speech output. i-Math generates a correct Thai pronunciation for an input using the developed THsound rule-based system. i-Math collects the sound units in five categories and employs the TD-PSOLA model to smooth the concatenation and control the pitch and duration for synthesize the natural-like Thai speech.

i-Math was used in Mathematics classes of 7–9 grade level in two secondary schools for blind and VI students. The evaluation results indicate that i-Math is able to produce acceptable speech output with intended meaning. In educational environment, i-Math gives students a sense of independence and confidence in studying mathematics. With i-Math, students can enjoy their newfound ability to read and study anytime, anywhere. In addition, participants' responses also affirmed that both teachers and students had positive perception toward the use of i-Math.

With the capability to access math material of i-Math, i-Math can help blind and VI students in learning mathematics better since the students can conveniently and individually practice and study mathematics on their own. Meanwhile, i-Math can be applied to promote educational technology in a mathematics classroom.

For future research we intend to resolve the reading ambiguity of some expressions, e.g., 2^{x+5} and $2^x + 5$. In doing so, extra word addition must be revised, and prosody information must be considered. Moreover, the ability of i-Math will be enhanced to read more complicated expression e.g., the integral and limitation expressions. Additional research is also required for extending the ability of i-Math to read math expressions in open standard such as PDF, HTML, or text.

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