

Conversion of 2D Mathematical Equation to Linear Form for Transliterating into Braille: An aid for Visually Impaired People

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ABSTRACT: Mathematics has been penetrated in each and every field, so the inevitability of dealing with Mathematical text is not only significant for mathematicians, but it is also an important need for anyone who wants to exert in any Mathematics as well as scientific field. But for visually impaired people, functioning with mathematical content is one of the biggest hindrances; as the mathematical expressions can be present in 2D form. In this paper, researcher has discussed on the issues in representing mathematical text into Braille and further, the researcher has also provided solution to it. The tool is designed and developed that convert's mathematical text into Braille. Rules are created, transformation table is formed, mathematical notations are recognized and it is converted into the linear form which can be easily transliterated into Braille for blind people. Braille content generated is stored into the text file which can further be printed on embosser. Braille document generated after the transliteration are tested by Braille experts – teachers teaching Braille. After the verification of the output documents by the Braille experts, they agree with 98.70% of accuracy and it shows satisfactory results. It will also be useful to visually impaired students in learning mathematics.

KEYWORDS: Mathematical expression, Optical character recognition, Template matching technique, Braille, Visually impaired people.

I. INTRODUCTION

Mathematical notations are the heart in understanding and modelling sciences. Teaching mathematics to visually impaired individual is vital for the same reason that is essential for sighted individual. The study of mathematics enhances educational and occupational opportunities for all people [1]. But the mathematical expressions are very difficult to access by visually impaired people due to its visual and spatial nature. Fundamentally, reading and writing text is different from reading and writing mathematics [2]. As the mathematical content can be present in 2 Dimensional form, so, very less number of visually impaired people can acquire degree in scientific speciality and it also limits the job opportunities and study options for blind people [3].

Before elaborating the design and development of the tool, it is essential to describe and shed light on certain amount of background information regarding mathematical notations, Braille and access to mathematical material for visually impaired people.

a) Mathematical notations

Due to the visual and spatial feature of mathematics, variety of notations and representations has evolved. As meaning in mathematics must be very precise, notation reflects that there is no duplication in mathematical expression and syntactically similar equations may have different meanings [4]. As observed, the nature of text is linear whereas the nature of mathematical expressions can be two-dimensional [2]; as it conveys general structure of the equations and it also facilitates the sighted reader to understand it. Linear nature means all the letters must be on the same line and does not span over more than one line in height [5]. Fig. 1 shown below represents equation in linear form.

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2Dimensional mathematical equation means the letters within the equation can span more than one line in height. Fig. 2 shown below represents 2D equation. There are various expressions such as fraction, superscript, subscript etc are also represented as 2D.

$$\{4+ [3 + (5 - 1)]\}$$

Fig. 1. Linear Equation

$$\left(\frac{9}{12}\right)^2 - \left(\frac{8}{12}\right)^2 \text{ --- EQ (1)}$$

$$2^5 \times 2^8 \div 2^6 \text{ --- EQ (2)}$$

Fig. 2. 2D Expressions

b) Braille Math

Braille is a tactile writing system used by visually impaired people which is written in embossed form [6]. It is written on the thick sheet of paper in the form of cells that are made up of raised dots. Each cell has 6 dots (2 wide and 3 tall); arranged in the form of rectangular grid. So total 64 i.e. 26 unique characters can be represented in Braille [7] and [8]. Generally text and numbers are represented with literary Braille code developed by BANA (Braille Authority of North America) [9]. To help visually impaired people to do mathematics, different Braille specific notations have been developed during last few decades like Marburg in Germany (1946) and Nemeth code in United States (1972) [10]. Fig. 3 and Fig. 4 as shown below represents Literary Braille Code and Nemeth Braille Code respectively [11].

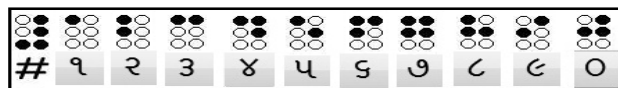


Fig. 1. Literary Braille Code

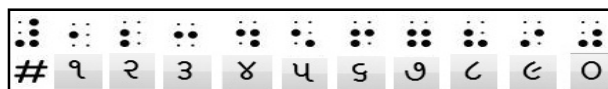


Fig. 2. Nemeth Braille Code

As represented in Fig. 3 and Fig. 4, Literary Braille code are formed using upper part of the Braille cell, dots 1, 2, 4, 5 and Nemeth Braille code are formed using the dots 2, 3, 5, 6 from the lower part of the Braille cell. Fig. 5 as shown below represents common Mathematical Symbols in Braille code.

Symbol	>	<	≥	≤	≠	≅		
Braille								
Symbol	+	-	×	÷	=	.(decimal)	√ (radical index)	∛ (radical index)
Braille								
Symbol	()	[]	{	}		
Braille								

Fig. 3. Mathematical symbols in Braille

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c) Issues related to Braille math

There are some similarities in teaching and learning of traditional mathematics instruction and mathematics in a tactile mode. Traditional mathematics relies on spatial, visual and abstract concepts that are challenging for visually impaired people. Therefore, the difference between traditional mathematics and Braille math must be taken into consideration, while generating content in mathematics for blind people.

The nature of Braille math is linear. So linearity is the important issue need to be considered while converting mathematical notations into Braille. As known superscript, fractions, subscript, spatial function such as summations etc have 2-Dimensional form and if they are need to be converted into Braille then it must be converted into its linear form. For instance, as shown in Fig. 2, the equations are represented is in 2-dimensional form and if they are linearized, then the first equation is represented as $(9/12)^2 - (8/12)^2$ and second equation is represented as $2^5 \times 2^8 \div 2^6$. This type of expressions required special attention to avoid ambiguity.

The process of linearizing the equation may need to add extra parenthesis or brackets, additional operators etc. For instance, to represent superscript, '^' (carat) can be added in the equation. So the process of linearization increases the size of the equation and it becomes difficult to read.

Furthermore, the character set of Braille math is very limited, as with 6 dots Braille cell layout, only 64 unique characters can be formed. So, while representing mathematical equations, many characters are to be embedded along with numbers. These characters are referred to as modifier symbol / escape characters / indicators as shown below in table 1. This too increases the size and complexity of the mathematical equations.

Despite of these issues; mathematical content is needed to be linearized to represent it into Braille.

Pins on Printer	ASCII character	Braille Character	Meaning
Braille indicators			
Braille p456	-		Punctuation
Braille p45	^		Superscript
Braille p56	;		Subscript
Braille p5	”		Beginning (Baseline)
Braille p123456	=		Omission
Braille p246	[Cancel (open)
Braille p12456]		Cancel (close)
Braille p126	<		Directly Over
Braille p146	%		Directly under
Braille p12456]		Termination
Braille p1246	\$		Shape
Braille p3456	#		Digit prefix #
Braille p45	^		Letter sign
Braille p4	@		Half character

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












Braille p6	,		Capital character
Braille p6, p6	,,		Capital word
Roman Numerals			
Braille p6, p24	, i		One I
Braille p6, p1236	, v		Five V
Braille p6, p1346	, x		Ten X
Braille p6, p123	, l		Fifty L
Braille p6, p14	, c		Hundred C
Braille p6, p134	, m		Thousand M
Other Symbols			
Braille p46	.		Decimal point
Braille p6	,		Maths full stop
Braille p		<space>	32
Braille p46, p1234	. p		Phi π
Braille p345	>		Square root $\sqrt{\quad}$
Braille p4, p356	@ 0		Percentage %

Table 1 Modifiers and other symbols of Braille Math

d) Related work

Dominique Archambault [3] has analysed the non visual modalities for accessing mathematical content to blind people. Author has also described the state of art and discussed about the accessible math content. Arthur Karshmer, Gopal Gupta and Enrico Pontellic [12] have discussed about 2-dimensional nature of mathematical equations and its difficulty to convert it into Braille as the character set of Braille is limited. Authors has also described that non visual modalities need to be consider to convert mathematical equations into Braille by converting it in linear form. Alistar Edward, Heather McCartney and Flavio Forgardo [4] have discussed overview of Mathematical notations, difficulty and complexity raised due to smaller character set of Braille in deriving linear form of equations from 2-dimensional nature. Authors have also discussed on the Lambda project that work by considering MathML which is XML based notations for representing mathematics. Dominique Archambault, Bernhard Stoger, Donal Fitzpatrick, Klaus Miesenberger [13] has described modalities that is to be used to render mathematical content and also describes speech and Braille as solutions along with other research projects related to Braille conversion. Marc Bitter [5] has given comparative study on Dutch Braille codes that supports mathematics. The author has used literature research and interviews methods to describe complexity of mathematical notations and compare different Braille codes. Marion Haresh [14] has described that due to the less characters present in Braille script, need arises to add extra modifiers while representing mathematical content for blind people; it becomes difficult to work with mathematical equations in Braille. Author has also given the approach based on speech and Braille from Latex and MathML. S. Maddox [15] has described various standards used to represent Braille math. Author has described complexities with respect to linearizing equations for representing mathematical notations into Braille. Author has also discusses several ways such as Latex files, MathML etc and also discussed about Duxbury Braille Translator tool available for the conversion of

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Text to Braille. But author described that the ways provided does not work for representing Braille math. M. Jarmar [16] has develop system that provides accessibility of mathematical documents to visually impaired people. Author has also discussed the complexity in deriving mathematical equations for blind people and along with that author also described an existing solution for this approach. Author has tried to implement Czech Braille output module for UMCL library, but as UMCL itself is erroneous, So proper solution was not been developed. M. Victor and A. Dominique [17] and [18] have developed a project for converting Mathematical expressions into Braille. Input is the equations written in MathML or LATEX and output is the Mathematics Braille for French. P. B. Stanley and A. I. Karshmer [19] have worked on converting MathML into Nemeth Braille Code. With the help of equation editor, they translated equations into MathML; translated equation is saved and then converted into Nemeth Code. So Math equation must be in MathML then only it can be converted into Braille. N. B. Jariwala and B. Patel [11] have developed the tool for the transliteration of Digital Gujarati Mathematical Text into Braille. The tool works perfect and gives satisfactory result for equations that are in linear form. But, 2D equations are directly not able to be transliterated into Braille. So the solution is needed through which 2dimensional equations can be converted into linear form.

As discussed in the literature review, many researchers have tried to provide solutions for the representation of mathematical text into Braille, but as described the solutions that are discussed depend on some language or software such as MathML, Latex, and UMCL library, Duxbury Translator etc. So first of all user need to have knowledge of it.

We aim to provide the solution that does not need the knowledge of any kind of software or language. A scanned copy of the document that contains 2-Dimensional equations is given to the proposed tool as an input which converts 2-Dimensional equations into linear form and then converts it into Braille as discussed in further section.

II. MATH EQUATION RECOGNITION AND TRANSLITERATION TOOL

a) Challenges and complexities

As discussed earlier in topic I(a), mathematical content contains equations in linear as well as in 2 dimensional format. Linear equations are easier to process with compared to 2D form as linear equations are written in a straight line and height is also not spanned over more than one line. For instance, equation in Fig. 1 is easy to process, as it spans over a single line. But equations in Fig. 2 are difficult to process. Equation 1 in Fig. 2 spans over 3 lines and equation 2 in Fig. 2 spans over 2 lines. Even if the letters and digits in equations spans over more than one line in height they are need to be process as a single equation.

Let's consider equation 2 of Fig. 2, it contains superscript notations. Due to the visual and spatial feature, by viewing the equation, it is very easy to determine that which digit is in base and which digit is to be considered in power. But when it comes to the processing the image of the equations, then it becomes difficult to identify that which letter / digit is to be consider as base and which is to be consider as power. If care is not taken then all the digits would be processed on a same line and the characteristic of the equation i.e. superscript will be lost.

If equation 1 of Fig. 2 is considered, it contains digits in numerator as well as in denominator and it also contains superscript. So again here at the time of processing, if it is not determined that which digits is to be placed where then the meaning and semantics of the equation may changed and the original form of the equation is lost.

Same complexity will arise if the equation contains letters and digits in subscript. More complexity is present if the single equation contains letters in linear as well as in 2D form. For instance equation 2 of Fig. 6, here letter 'I' and '=' are present in linear form, whereas 'PRN' are in numerator and '100' is in denominator. So it becomes difficult to determine the places of the letters and digits in the equation and it raises complexity while processing.

Likewise there are many possibilities and various types of equations which are to be taken into consideration while converting 2D equations into its linear form for transliterating it into Braille.

b) Math Equation Recognition Module

As discussed in literature review (topic I(d)), many authors have used Latex, MathML, XML etc for representing Mathematical equations in linear form. So the user must have the knowledge of particular language or software to convert 2-dimensional equations into linear form. The method discussed in this paper, is developed using optical character recognition technique. The input will be the image that contains mathematical equations. The equations can either be in linear or 2D formats. The method discussed will convert the equations present in the image directly into its linear form. So there is no need to have knowledge related to any particular language or software.

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For converting Mathematical text to Braille, the mathematical text must be in the linear form [12]. So for the recognition of Mathematical text from the image and converting it into linear form, Math Text Recognition module is implemented using MATLAB. Individual characters are extracted from the inputted image and then extracted characters are recognized using Template Matching Technique. To accomplish the task character recognition steps are as follows:

- Pre-processing and Morphology: The input is the scanned image that contains mathematical equations. Pre-processing steps converts the document image into binary and by applying morphological operation, noise is removed and skewness is corrected. Fig. 6 shown below represents the inputted image in grayscale.
- Binarization: inputted scanned image is converted into grayscale (binary image).
- Noise removal: remove unwanted bit which may degrade the quality of the image.
- Skew detection and correction: the angle that the lines of text in the digital image make with the horizontal direction is called skew angle. Sometimes the image may be skew by some degree. The angle of skewness is detected and corrected. So the text in the image appears in a straight line.

(1) $10 - \{8 + (4 \div 2)\}$
(2) $I = \frac{PRN}{100}$
(3) $7 + \{3 + (5 - 3)\}$
(4) $2x - 8 = 16$
(5) $2^5 \times 2^8 \div 2^6$

Fig. 4. Binarized (Grayscale) image

- Segmentation: The cleaned up image obtained as output of pre-processing stage serves as input to the segmentation stage, which refers to decomposing the document into sub components. The image may contains equations in linear as well as in 2D form. Here linear equations may not create problem; if the whole image is processed at a time, as the text is written on the same line i.e. height of the text is also one line. But if we consider 2D equations, then they span to more than one line i.e. height of the text is more than one line as shown in Fig. 2 and still they are need to be considered as a single equation. So as discussed in topic II (a) there are complexities in processing 2 dimensional equations from the image. So the whole image cannot be processed at a time. But if the image is decomposed into small components then it might reduce the complexity. So the image is segmented into lines, lines into words and words to characters. The process by which the objects in the image are separated is called segmentation. Fig. 7 shown below represents text line segmentation. Fig. 8 represents word segmentation and Fig. 9 represents character extraction.

(1) $10 - \{8 + (4 \div 2)\}$
(2) $I = \frac{PRN}{100}$
(3) $7 + \{3 + (5 - 3)\}$
(4) $2x - 8 = 16$
(5) $2^5 \times 2^8 \div 2^6$

Fig. 5. Segmentation (Text line extraction)

As shown above in fig. 7, the image is decomposed into 5 lines using projection profile and horizontal run calculation. Height of the line is calculated by considering the minimum value of y co-ordinate of the characters and maximum value of the y co-ordinate of the characters. According to the value determined the height of the line is calculated and the lines are segmented from the image.

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Fig. 6. Segmentation (Word extraction)

As shown above in fig. 8, to segment words from the lines, the fore-color is converted into white and back-color is converted into black. Then according to inter-word (the space between two words) and intra-word (the space between the characters within the words) distances words are segmented. From the observation of the dataset, threshold of 10 pixels is considered for calculating and segmenting the word.



Fig. 7. Character extraction

As shown above in fig. 9, characters are extracted from the words by labelling the connected component.

- Feature extraction: each character has its own special properties or parameters through which it is represented. So to find the special properties or parameters of the characters is called feature extraction.
- Recognition: the attention of the authors is towards the educational content and as per the observation of the authors; font type, its size and style are pre-defined if text books are concern. So pre-defined database of the characters and symbols is created and Template matching technique is used for the recognition of the characters extracted from the image.

Steps of Math equations recognition algorithm are as follows:

- Step 1: Read Image file (imread)
- Step 2: Convert it into Gray scale (rgb2gray)
- Step 3: Remove noise if any (bwmorp)
- Step 4: Lines are segmented using projection profiles and horizontal run calculation.
- Step 5: Convert the segmented line into black and white (graythresh, im2bw)
- Step 6: Words are segmented from the segmented line by calculating inter-word and intra-word distance of connected components by comparing it with the threshold (10 pixels).
- Step 7: Character is extracted from the word by labelling connected component and by plotting bounded box around the character (bwlabel, regionprops)
- Step 8: Extracted character is recognized using template matching technique.
- Step 9: Once the character is recognized, check the feature to determine whether the character recognized lies in 2D equation or in linear form.
- Step 10: Position of the character is determined from the middle of the height of the word by following the rules. According to the position of the character it is determined that the character is in denominator, numerator, subscript or superscript etc.

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Step 11: Recognized character is added into the text file.

Step 12: According to the position of the character; indicator / modifiers / escape character as shown in table 1 are added in the text file.

Step 13: File that is generated after the execution of the steps from 4 to 12 is given to the Mathematical Tool for transliterating the text into Braille.

The text file generated that contains mathematical text in linear form can be further given as an input into Mathematical Tool for transliterating the content into Braille.

c) Mathematical Tool

The mathematical tool discussed in [11], is used for the transliteration of Mathematical text into Braille. Rules are defined and transformation table is created which contains mathematical symbols and its corresponding Braille character. Character mapping technique [20] is used for mapping the characters from the inputted text to the characters in transformation table for the conversion of Mathematical Text into Braille. Input to the tool is the text file generated after the conversion of 2D equations into linear form by using the Math Equation Recognition Module discussed above in topic II(b) and after processing the math text; the output is generated which is the Braille text. Here the concentration is done on both Nemeth code and literary code (discussed in topic I(b)) and mathematical content is converted into both the Braille notations according to the Standard American Grade 0 [21].

III. TESTING AND RESULT

Dataset of 203 different image files of .jpg format is considered for testing Math Equation Recognition module of Mathematical Tool. These images contain text written in different type and size of fonts such as Times New Roman, Arial, and Calibri with 10, 12, 14, 16, and 18 size as shown below in Fig. 10.

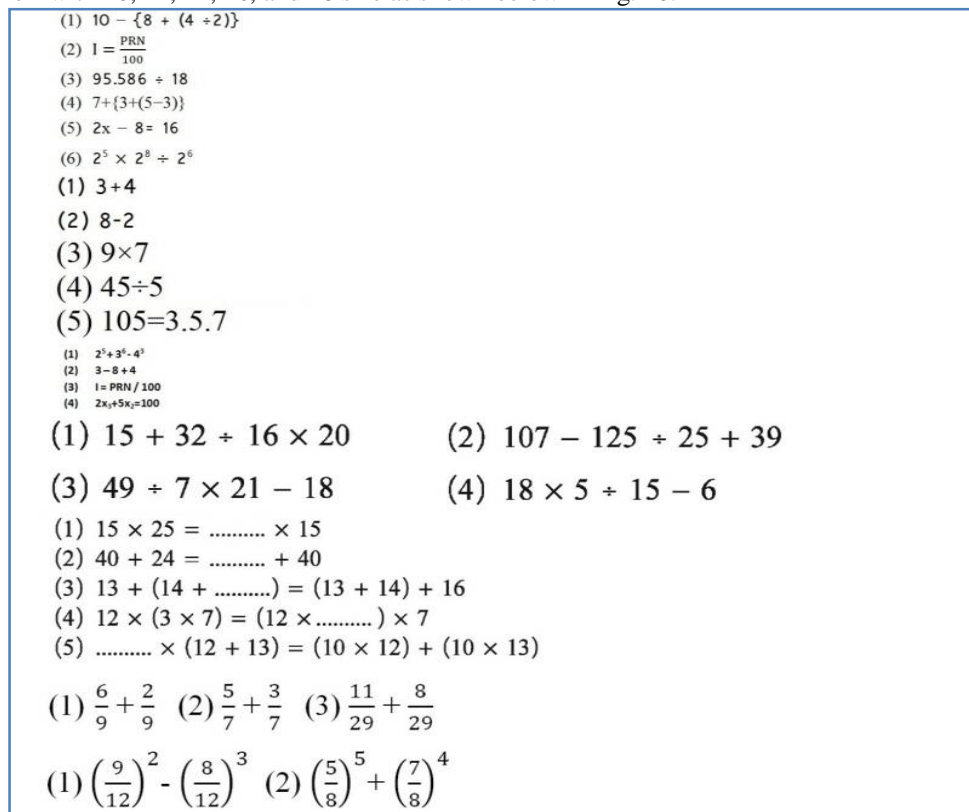


Fig. 8. Mathematical Text image file

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Out of these 203 image files, 77 files contains only 2 dimensional equations in it; from which 20 image files contains text with same font type and size and left over 57 files contains text with different font type and size in a single file. Remaining 126 image files out of 203 files contains linear as well as 2D equations in a same file; from which 27 files contains text with same font type and size whereas left over 99 files contains text with different font type and size in a single file.

Math equation recognition module recognizes the symbols and digits from the image and converts it into linear form for the transliteration into Braille. Fig. 10 shows image that contains Mathematical equations that are inputted into the system. Fig. 11 shown below represents text file that is generated as an output of Math Equation Recognition Module. Fig. 12 shows the output in Braille format i.e. in both Nemeth Code (Right Top box) and literary Code (Right Bottom box) of mathematical tool.

```
(1) 10 - { 8 + ( 4 + 2 ) }
(2) I = PRN/100
(3) 95 . 586 + 18
(4) 7 + { 3 + ( 5 - 3 ) }
(5) 2X - 8 = 16
(6) 2^5 x 2^8 + 2^6
(1) 3 + 4
(2) 8 - 2
(3) 9 x 7
(4) 45 + 5
(5) 105 = 3 . 5 . 7
(1) 2^5 + 3^6 - 4^3
(2) 3 - 8 + 4
(3) I = PRN / 100
(4) 2X-3 + 5X-2 = 100
(1) 15 + 32 + 16 x 20 (2) 107 - 125 + 25 + 39
(3) 49 + 7 x 21 - 18 (4) 18 x 5 + 15 - 6
(1) 15 x 25 = ..... x 15
(2) 40 + 24 = ..... + 40
(3) 13 + ( 14 + ..... ) = ( 13 + 14 ) + 16
(4) 12 x ( 3 x 7 ) = ( 12 x ..... ) x 7
(5) ..... x ( 12 + 13 ) = ( 10 x 12 ) + ( 10 x 13 )
(1) 6/9 + 2/9 (2) 3/7 + 3/7 (3) 11/29 + 8/29
(1) ( 9/12 )^2 - ( 8/12 )^3 (2) ( 3/8 )^3 + ( 7/8 )^4
```

Fig. 9. Text file of Mathematical text in linear form

The mathematical tool is tested on the text collected from the math books of standard 1 to 7 and from the document such as question papers, practice material typed by the teachers that are provided by the math teacher of Blind Student School, Surat. The document transliterated from the Mathematical tool are verified by the experts (Braille teachers) and it shows that proposed tool works perfect and gives satisfactory result with accuracy of 98.70% for the decimal numbers, arithmetic operators, comparison operations, various types of brackets, oblique sign, units representation and roman numbers, geometry notations, set theory symbols etc.

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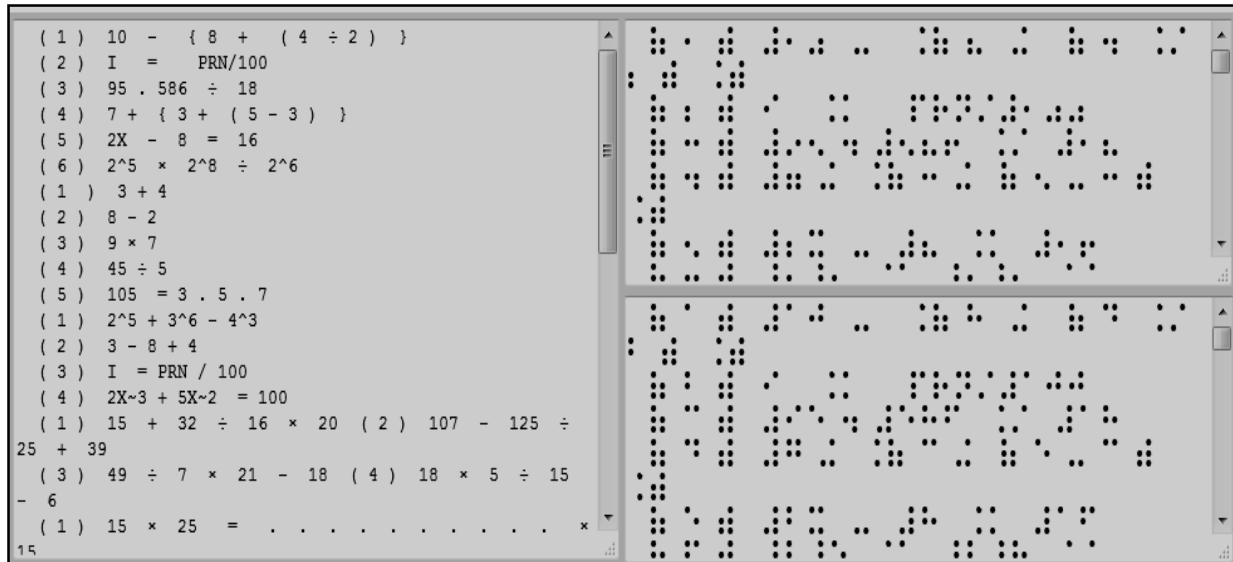


Fig. 10. Output of Mathematical Tool (Braille text)

IV. CONCLUSION

The Math equation recognition module of mathematics transliteration tool is developed as a solution for the conversion of 2-dimensional mathematical equations into its linear form, so that further the mathematical text in linear form can be transliterated into Braille for visually impaired people. The text generated in linear form and transliterated Braille content is tested by the experts and they agree with the accuracy and the result generated by the tool. It has also changed the way of teaching mathematics to the visually impaired students and it shows improvement in the way of learning.

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