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Research on improving communication between the blind and the sighted in the area of mathematics, and related requirements

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Abstract—**Attempts to allow the blind to read and write mathematical texts have been made for many years. Such research is conducted both in Poland and abroad. Nevertheless, there is still no complex solution to this problem that would satisfy the users thoroughly. The greatest difficulty facing blind and sighted individuals working on texts containing mathematical formulae together is that in sighted people's notation, these expressions take form of two-dimensional sets of graphical symbols, while Braille provides linear, often context-dependent notation for such expositions. This paper presents identified cases of work and education in mathematics that require new technologies to improve cooperation between the blind and the sighted who do not know Braille nor Braille Mathematics Notation. The research initiated by the Institute of Mathematical Machines discussed herein is aimed to develop innovative technologies that will improve communication, Web-based and else, between blind and sighted individuals in the area of mathematics.**

I. Introduction to the Problem

IFOR MANY years attempts have been made to enable blind people to read and write texts in mathematics unaided. Research in this field is conducted both in Poland and abroad. Nevertheless, there is still no comprehensive solution to this problem that would satisfy the users thoroughly. The greatest difficulty facing blind and sighted individuals who work on texts containing mathematical formulae together is that in sighted people's notation, these expressions take form of two-dimensional sets of graphical symbols, while Braille, used by the blind, provides linear notation for such expositions. Another problem is that the semantic interpretation of individual symbols used in such linear notation is often context-dependent, and varies depending on the adjacent symbols, the presence of a space before or after the symbol, etc. An automatic translation between these two ways of expressing the mathematical language is a fairly complex problem.

There are any solutions available on the market that provide to write mathematical formulae by the blind people that are accessible to the sighted. Some of these solutions also gives possibility for the blind to read texts in mathematics prepared by the sighted. Unfortunately, they are only limited possibilities. Some methods, such as writing formulae using the Equation Editor in MS Word, or reading mathematical papers in electronic (PDF, PS) or paper form, are completely inaccessible for the blind. Others, such as writing equations in several LaTeX-based editing environments, or in MS Office, present considerable difficulties of various sorts for the blind. The blind are able to write mathematical texts using Braille notetakers. Notation used therein, however, is completely undecipherable for the sighted that are not acquainted with Braille and the set of Braille Mathematics Notation rules and symbols. Other solutions to this problem developed over the recent years, such as the Translator+Homer system [2], or the MathPlayer plugin for Internet Explorer [3], are either imperfect or not fully adapted to the requirements of Polish and other non-English Speaking Users. For these reasons it is necessary to undertake research on technologies in order to improve communication between the blind and the sighted in the area of mathematics. Such research is currently conducted by the Institute of Mathematical Machines in Warsaw. It focuses on developing a coherent technology for convenient processing (input, editing, formatting and printing in Braille) of mathematical texts and auxiliary drawings by blind and sighted users. The developed technology will also improve almost-real-time and offline communication between the blind and the sighted in the area of mathematical problems (preparing Braille publications cooperatively, or solving problems interactively by blind students assisted by sighted teachers). The term "almost-real-time" refers to the possibility of passing mathematical formulas between blind and sighted users immediately upon completion of input, allowing for the time required for conversion to Braille or speech, and transmission.

II. State-of-the-Art Technologies Supporting Communication with the Blind in the Area of Mathematics

Currently, there are solutions available on the market that provide only limited possibilities for the blind to write mathematical formulae accessible to the sighted and read texts in mathematics prepared by the sighted. Some of these require developing specialist skills and techniques, which is beyond the reach of a novice user, e.g. a blind primary school student.

The greatest difficulty facing blind and sighted individuals who work on texts containing mathematical formulae together is that in sighted people's notation, these expressions take form of two-dimensional sets of graphical symbols, while Braille, used by the blind, provides linear notation for such expositions. The most conventional way of writing mathematical expressions by the blind consists in using Braille slates or braille typewriters, and the Braille Mathematics Notation (BMN). For example, the formula: $Y = \frac{1}{4}X$ expressed in notation of sighted, in braille (BNM) notation will get a linear form: `Y =#a/_X`. So we can see that this method of writing mathematic requires teachers to know both the Braille alphabet and the set of symbols constituting the Braille Mathematics Notation.

One of the oldest ways of using computer equipment to enable the blind to write mathematical expressions unaided (allowing these at the same time to be read by the sighted who do not know Braille) is the LaTeX system/language [1]. LaTeX is a professional typesetting system for the sighted that supports, among other things, mathematical expressions. It can be successfully used by the blind, since mathematical formulae are expressed therein in a linear form, as in BMN. For example, the blind person without problems can write LaTeX command: `$Y =\frac{1}{4}X$` and after compilation of the source document he will get its graphical representation: $Y = \frac{1}{4}X$ i.e. in pdf form. This representation may be recognized by a sighted person. Also the partially sighted individual can see this result in magnified form. The greatest difficulty facing a common use of the LaTeX language is that although it is possible to convert the written text to its graphical representation, a blind user does not have an absolute control over the final appearance of documents. Another problem is that creating documents in LaTeX requires the user to learn several dozen language-specific commands, as well as methods of compiling the source code into the graphical representation. Moreover, LaTeX commands are relatively long, which makes quick input of mathematical expressions (e.g. by a student, during a lecture) virtually impossible. Hence, this method is suitable neither for novice users, such as primary school students, nor for primary school teachers, who usually do not know the LaTeX language.

A common way of the sighted to write mathematical expressions is the use of the Equation Editor in MS Word. Unfortunately, this is utterly useless for the blind, since formulae are created therein mostly using the mouse, and a blind person's ability to use this device is very limited. Microsoft partially resolved this issue by introducing linear mathematical notation, hereinafter referred to as Unicode Math (after [4]), in MS Word 2007 (unofficially) and MS Word 2010 (officially). It allows inputting mathematical formulae using appropriate text commands and keyboard shortcuts. One downside of using this solution is that a blind person cannot amend the formula being written. This is caused by the fact that the Equation Editor is not supported by computer screen reading software used by the blind, such as Jaws or Windows Eyes [5], [6] i.e. the screenreader program can read expression 1/4 but it does not read $\frac{1}{4}$ that is generated by an equation editor. Besides, as is the case for the LaTeX language, using the Unicode Math notation requires the user to learn its specific commands. These, like LaTeX commands, are formulated in English, which poses a major difficulty for non-English speaking users and people who barely started learning this language.

One of the recently developed solutions is the aforementioned dedicated Internet Explorer plugin called MathPlayer [3]. It allows reading mathematical formulae placed on websites in the form of MathML language tags using speech synthesis. Design Science, the developer of the MathPlayer plugin, also offers a tool for creating mathematical formulae, exporting equations from MS Word and writing them in a website format supported by MathPlayer. Both the MathType tool and the MathPlayer plugin are available in English only, which may pose a difficulty, especially for novice Polish users. Another limitation of MathPlayer is that it does not read formulae expressed using the Unicode Math notation.

Over the past ten-odd years, several computer programmes have been developed that allow printing texts for the blind using standard and professional Braille printers. One such programme is WinBraille, which is delivered with Index Braille printers. It allows editing both simple and more complex Braille texts based on MS Word documents. WinBraille provides no special functions for editing mathematical texts; formulae have to be put directly in the edited Braille document. This requires knowledge not only of the Braille alphabet and BMN, but also of the Braille-QWERTY keyboard charts which govern printing Braille symbols. For example, when user will press the sequence `#a` on a qwerty keyboard, it will produce braille digit 1. WinBraille also provides a Braille keyboard simulation, where pressing ”F”, ”D”, ”S”, ”J”, ”K” and ”L” simultaneously results in printing corresponding Braille characters. For example, when user will press ”f”, and ”d” that coresponds to 1 and 2 braille point it will produce letter ”b”. Although the WinBraille user interface is in English, adequate code tables that are attached to the software allow users to edit Polish documents by writing appropriate BMN symbols using qwerty or braille keyboard. WinBraille also allows inserting simple drawings in Braille documents; these may be imported from BMP files or MS Word documents. This solution, however, does not support all Braille printers. Moreover, according to the latest information found on the developer's website [11], this product will not be further developed.

Another popular Braille text editing programme is Duxbury [7]. Its function is very similar to that of the already mentioned WinBraille. As in WinBraille, mathematical formulae can be input in Duxbury directly in the already edited Braille text, by writing appropriate BMN symbols using the keyboard. This programme also provides a function for importing mathematical equations expressed in the LaTeX language. Since Duxbury is an American programme, the mathematical notation it generates is not consistent with the one used in Europe, including Poland, which is based on professor Epheser's works [8]. Thereby, the function of Duxbury that allows importing LaTeX equations is not suitable for Polish users; instead of using it, they have to input BMN symbols manually in the edited document.

As computer techniques progressed and spread, various electronic notetakers equipped with a Braille or QWERTY keyboard, a speech synthesis module, and often a Braille line appeared on the market. These devices are an attractive alternative to conventional Braille typewriters, as they allow the blind to edit texts quickly. Braille notetakers provide functions for reviewing texts and exporting them to computer formats easily. They allow blind users acquainted with Braille Mathematics Notation to edit texts containing equations and print those using Braille printers. However, mathematical formulae expressed this way are not transparent for users who do not know BMN. Opening them in common text editors results in displaying series of meaningless symbols. The example of popular braille notetaker Braillesense is presented on figure 1.

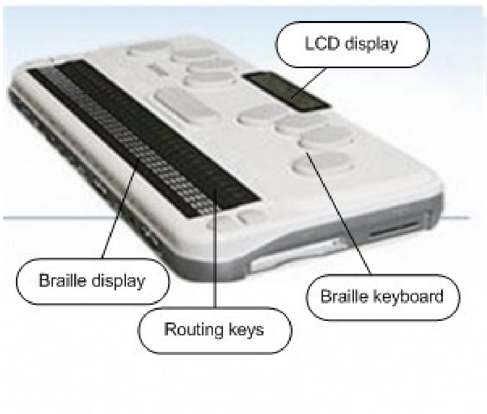

Fig. 1. Braillesense notetaker

Attempts to solve the problem of communication (between a blind student and a sighted teacher) in terms of writing and reading mathematical formulae have also been made in Poland. The oldest programme used for editing Braille texts is Brajl. It is run under DOS. QRTekst editor files and text files may be imported and used as its input documents. For many years it was very useful solution so many textbooks, including mathematical ones, were edited using this program. Mathematical formulae may be written in Braille in the source text, as was the case for the afore-mentioned WinBraille, but it requires the editor to know BMN and be aware of what characters input using the keyboard correspond to mathematical symbols used in this notation.

The most complex solution to the problem of editing mathematical Braille texts developed so far is a project undertaken in the Institute of the Computer Science of the Polish Academy of Sciences in 2002. It resulted in developing a programme called Translator [2]. It allows converting mathematical formulae written in the LaTeX language to the form of (modified) Braille Mathematics Notation. Consequently, an application called Homer was developed that acts in the opposite way, converting formulae written in Braille to the Latex format. A software suite consisting of these two translators and an interface for Windows users is called Euler. For the purpose of the project, its creators developed modified Braille Mathematics Notation, which extends the earlier professor Epheser's notation with numerous symbols and functionalities, such as the zero record column and a wide range of typeface definitions.

The imperfections of Euler, as well as the use of an unknown, complex Braille notation resulted in its unpopularity among Polish mathematics teachers (working mostly in special schools for the blind). On their initiative simplified BMN was developed and adopted by the Ministry of National Education as the official Polish notation [9].

Recent attempts to define clear rules and ways of editing Braille texts containing mathematical formulae have been made within the "Education, disability, information and technology. Eliminating barriers for the disabled to access education" project [10] undertaken at the University of Warsaw. It resulted in releasing a publication that defines the rules of editing electronic, Braille and large-print documents. It also describes the ways of conducting such activities, and provides indications for the methods of editing Braille texts containing mathematical formulae. Within the project, a set of MS Word macro commands have been developed that convert mathematical formulae in the form of text containing LaTeX commands to the official BMN notation. LaTeX commands are obtained from Word documents using Word2TeX programme offered on the market, which converts MS Word text documents and the Equation Editor or MathType notation formulae contained therein. It does not, however, convert the new linear Unicode Math format to LaTeX.

III. NEEDS FOR NEW SOLUTIONS

The results of research on new technologies should meet the needs for facilities and improvements in:

- processing (input, editing, formatting and printing in Braille) texts containing mathematical formulae and auxiliary drawings prepared by the blind and the sighted, and intended for the blind,
- almost-real-time and offline communication between the blind and the sighted in editorial processes of mathematical texts, collaborative work on new mathematical textbooks and teaching aids, teaching mathematics, solving tests and examination problems by blind students, and evaluating their solutions by sighted teachers or tutors.

Improvements are required in such areas as:

- preparing mathematical texts for Braille printing by the blind, in LaTeX and MS Office environments (publishing);
- editing mathematical texts for the purpose of Braille printing by the sighted, in LaTeX and MS Office environments (publishing);

- teaching mathematics to blind students by sighted teachers and tutors who use existing printed (black-and-white, Braille) or electronic (RTF, TXT, PDF) mathematical texts and exchange mathematical texts (e.g. problem solutions) with each other by various means, including the Internet.

It would also be facilitating and improving to:

- enable quicker input of mathematical formulae for the purpose of converting them to Braille;
- input formula-related mathematical drawings for the purpose of converting them to Braille;
- automatically format mathematical texts initially saved in LaTeX or MS Word as properly structured Braille documents;
- directly convert mathematical formulae contained in MS Word documents to Braille;
- convert mathematical texts from MS Word to LaTeX;
- automatically convert the layout of mathematical MS Word documents to that of Braille notation;
- semantically (intelligently) render mathematical formulae contained in MS Word documents to sound, perhaps using Web services;
- automatically convert documents containing mathematical formulae created using Braille notetakers to MS Word format.

IV. Scope of research

The research will cover problems related to the automation of data and document exchange between the MS Word 2010, LaTeX and Braille environments in order to enable the user to get the most of what matters to him or her, e.g. efficiency, quality of results, ability to cooperate with another human being locally or remotely, out of each environment. The research problems will concern:

- LaTeX, Unicode Math and BMN notation interoperability, and related issues of recognisability and conversion of formulae, as well as reliability and necessary heuristics;
- semantic (remote and local) techniques of intelligent online text-to-speech readout of mathematical formulae;
- inserting mathematical drawings of a known location in the black-and-white text in specific places within the Braille text;
- transferability of styles, formatting, views, pagination, tables of contents, and other elements, and its reliability, in the following combinations:
  - from MS Word documents to Braille documents,
  - from MS Word documents to LaTeX documents,
  - from MS Word documents to LaTeX documents, and then to Braille documents,
  - from Braille documents to MS Word documents.

In order to provide the blind with working and learning techniques related to mathematical documents that are more efficient than those already existing, the following manner of solving the research problem has been adopted:

- extending the developed technology with the new linear Unicode Math formula notation, which is available in MS Office 2010 (unofficially also in MS Office 2007);
- extending the editorial process with manual input of formulae by sighted teachers and workers, using the mouse, the keyboard, or a digital pen;
- allowing the blind to review formulae in the Unicode Math format by rendering them to sound (e.g. $a \times b$ to "a times b"); depending on the results of the research, this semantic sound rendering may be based on Web services, or on a local synthesiser used by screen reading software;
- allowing transferring mathematical texts, including their formatting, from the MS Word 2010 environment to the LaTeX environment, and to Braille - directly or via LaTeX; the research will cover techniques and possibilities of transferring text via Clipboard and RTF documents, respecting the Unicode Math, OMML and MathML standards;
- allowing transferring texts containing mathematical formulae created and saved in the BMN format by the blind, using Braille notetakers, to the MS Word 2010 environment.

The new technologies developed as a result of the research will allow:

1) quicker communication in the area of mathematics:
   - between a sighted teacher who does not know Braille and writes mathematical formulae in MS Word 2010, and a blind student receiving mathematical texts in BMN on a Braille line or a Braille printer,
   - between a blind student who writes formulae in simplified BMN (with abbreviations) using a notetaker or a computer with a Braille line, and a sighted teacher who does not know Braille and receives the written mathematical text as an MS Word document;
2) easier and quicker writing of mathematical formulae by the blind and the sighted, using a QWERTY or Braille keyboard;
3) printing documents containing mathematical formulae, including MS Word documents, using standard and professional Braille printers, and presenting them using Braille lines or speech synthesis.

V. Advantages of the developed solutions in comparison to the already existing ones

The main advantage of the developed solution will consist in the complexity of support for creating, exchanging, presenting and printing documents containing mathematical formulae expressed in BMN using intelligent speech synthesis and respecting proper document formatting. This complexity will ensure broad support for the blind and collaborating sighted people in the entire process of:

- publishing, from inputting text directly, using the keyboard (or obtaining it by converting from PDF, or by OCR

conversion of a scanned print), to obtaining a printed mathematical Braille publication;
- education in mathematics, related to solving problems with the help of textbook theory, and solving examination problems.

The advantage of the proposed technologies developed as a result of the research consists, among other things, in using the latest technologies, such as Unicode Math, an abbreviated format of mathematical formulae, and the electronisation of hand-written formulae, as well as innovative semantic Web services allowing converting mathematic formula text to speech intelligently. The new solutions will improve the efficiency of work and education of the blind in the area of mathematics, as well as their cooperation with the sighted, by:

1) accelerating mathematical text input and editing;
2) allowing inserting drawings in mathematical Braille texts;
3) facilitating reviewing formulae and supporting solving mathematical problems,
4) allowing printing formulae and presenting them in BMN on Braille lines;
5) creating a new production technology for Braille publishers, based on Braille printing of mathematical MS Word documents with the possibility of supplementing Braille notation with simple mathematical drawings;
6) allowing creating MS Word documents with a typical Braille document layout, intended for the sighted working with the blind.

The research and development activities will be conducted until the end of 2013. Their intensity and extent will depend on the magnitude of external funding, received, among other organisations, from the National Centre for Research and Development. The receivers of the results will include enterprises specialising in mathematical Braille publications, such as textbooks and teaching aids, special centres for blind children and young people, as well as public schools attended by blind students.

References

[1] H. Kopka and P. W. Daly, *"A Guide to LaTeX"*, 3rd ed. Harlow, England: Addison-Wesley, 1999.

[2] W. Wysocki, M. Kalbarczyk, and I. Busłowicz, *"Matematyczne pismo punktowe dla niewidomych (Mathematical Raised-Dot Writing System for the Blind)"*, Fundacja Szansa (published in Braille), 2002.

[3] Design Science *MathPlayer: Download and Installation.* Available at WWW: http://www.dessci.com/en/products/mathplayer/download.htm?src=mplogo.

[4] Murray Sargent III, *"Two Linear Formats Interoperable with MathML* Microsoft 2007". Available at WWW: http://www.activemath.org/workshops/MathUI/07/proceedings/Sargent-TwoSyntaxes-MathUI07.pdf.

[5] Freedom Scientific *Products for low vision, blindness, and learning disabilities from Freedom Scientific.* Available at WWW: http://www.freedomscientific.com/

[6] GW Micro *Window-Eyes 7.5.4.1 Now Available.* Available at WWW: http://www.gwmicro.com/.

[7] Duxbury Systems *Braille Translation Software from Duxbury Systems.* Available at WWW: http://www.duxburysystems.com/

[8] Helmut Epheser, *"Internationale Mathematikschrift für Blinde",* Marburg (Lahn), 1992.

[9] Colective work edited by K. Kauba, *"Brajlowska notacja matematyczna fizyczna chemiczna wydanie II. Publikacja rekomendowana przez Ministerstwo Edukacji Narodowej do stosowania przy przygotowaniu brajlowskich wersji podręczników, arkuszy egzaminacyjnych i materiałów pomocniczych",* Łódź, Bydgoszcz, Dąbrowa, Górnicza, Kraków, Wrocław, Laski, Lublin, Chorzów, Owińska, Warszawa, 2011.

[10] Uniwersytet Warszawski, *"Uniwersytet dla wszystkich BON - Edukacja, niepełnosprawność, informacja, technologia - likwidowanie barier w dostępie osób niepełnosprawnych do edukacji",* Biuro Osób Niepełnosprawnych Uniwersytetu Warszawskiego, Warszawa 2010. Available at WWW: http://www.bon.uw.edu.pl/likwidowanie_barier.html

[11] *"Index Braille".* Available at WWW: http://www.indexbraille.com/