Learning Math for Visually Impaired Users

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Abstract. Writing and reading formulas or perceiving the graph of a function stand in the way of a blind student for an efficient and complete study of Math. We propose an architecture made by different components that allows to a blind user to face the study of the mathematics in total autonomy. The system allows the formula editing, and the formula exploration. In case of the formula represents a 2D function, the system innovatively supports the haptic and audio exploration of the corresponding graph through a very cheap IO device. The article describes the system architecture and the test results.

Keywords: learning math, perception graphs, formulas, linearization, sonification, haptic feedback, aural feedback, visual impairments.

1 Introduction

Writing and reading formulas or perceiving the graph of a function stand in the way of a blind student for an efficient and complete study of Math. We propose a components architecture that allows to a blind user to face the study of the mathematics in total autonomy.

The mathematical coding doesn't enjoy for own nature of that linearity that instead it belongs, for instance, to a novel: the mathematical coding is not only a succession of known characters, as it is a word and therefore a sentence, but it uses a set of symbols, extension of the common alphabet, whose meaning depends on the position and on the relative dimension in which a symbol appears (above, under, apex). The use of specific symbols and the absence of linearity make the writing of mathematical formulas very complex in Braille.

Reading a formula is possible to define where each symbol is located and the location makes the meaning of each symbol well defined and unambiguous: this operation is called formula linearization. With this procedure it is possible to describe the formula and a blind user can understand it.

The Latex format can be an example of the formula linearization. Being used to write scientific documents it needs to store the formula and, of course, to handle well defined and unambiguous terms, but the Latex was not created to produce a linearization that a human user could easily understand.

Starting from the graph of a function, a student needs, for instance, easily perceive elements of primary importance as:

K. Miesenberger et al. (Eds.): ICCHP 2008, LNCS 5105, pp. 907–914, 2008.

- where the function grows or decreases
- where the maximums, the minimums and the flexes are
- where the points of discontinuity are

If the user knows the concepts that define the aforesaid elements, he can easily locate them on the function graph. In the same way, if he knows those concepts and where they are located, he can understand how the graph proceeds: for instance, after a maximum the graph decreases.

For the graph, which is an image, an operation such as the formula linearization is obviously unthinkable. In order that a blind student was able to build a mental map of the image, and therefore of the graph, he needs a system that uses stimulus on alternative senses.

2 State of the Art and Research Topic

Typically the two problems, reading and writing the formulas and perceiving the graphs, are managed by different environments.

For the reading and writing the formulas there are several efficient editors that are able to help a blind user in writing the formulas (i.e. Lambda Project [7] or BlindMath [6]). If they are very efficient for writing the formulas, they are not so efficient for reading: in order to grant the unambiguity, they typically read the formulas using a format which is distant from the human reading format.

For the graphs exploration there are several devices based on aural or tactile stimulus but they result not so efficient and they are very expensive, especially those based on tactile stimulus [1] [11].

3 Overview of L-MATH: The Proposed System

Starting from the previous remarks, we defined a components architecture that allows to a blind user to face the study of the mathematics in total autonomy. The insertion of mathematical formulas, their navigation and the exploration of their graphs, is supported using a multimodal approach. The graphs exploration is carried out by an innovative very cheap device that allows the images exploration using, at the same time, aural and tactile stimulus (AudioTact®[1] [4]).

The system is made up of four components, two for the formulas writing and reading, and two for the multimodal graph exploration:

- BlindMath [6]: is the very efficient editor that allows to a blind user the insertion of a formula and generates, as output, a Latex file. All is done using the keyboard and with the support of Jaws®, one of the most popular screen reader. During the editing, the Latex code is generated and showed in a graphical way so a sighted user can, if necessary, help the blind user.
- TalkingMath [8]: is the application that is able to read a formula in a very efficient way. It uses an original adaptative algorithm that modifies its behavior depending on the formula complexity. In this way, it reads the formula in the same way of the usual human reading complying with the unambiguity constraints.

[1] Copyright of Politecnico di Milano.

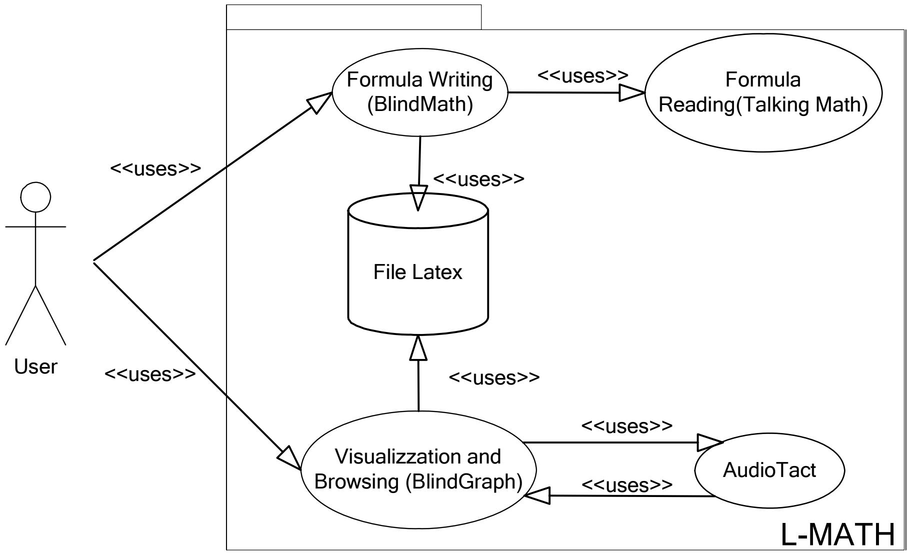

Fig. 1. L-MATH high-level overview

- AudioTact®: is the transducer of the multimodal stimulus.
- BlindGraph: is the software application that allows the graph exploration starting from a Latex file that describes the mathematical function.

The detailed description of the last two components follows.

3.1 AudioTact®: A Device for Multimodal Exploration

AudioTact® is an innovative device that allows a multimodal exploration of images. It is connected to the PC audio output and it is able to generate, at the same time, sonorous and tactile stimulus. The sounds are produced on the left audio channel; the vibrations are produced on the right audio channel and transmitted to the user applying a transducer to his finger - in case of a touch screen- or to the graphic tablet pen, otherwise.

The use of AudioTact® requires that the image is enriched with the information about where the stimulus must be generated and with the their attributes, such as the frequency and the volume of the sound.

The innovation introduced by AudioTact® is not only relied to the combination of sonorous and tactile stimulus but also to the simplicity of the used hardware. This means low cost and great facility in developing standalone or web applications able to use it.

3.2 BlindGraph: A Graph Editor

BlindGraph is the innovative application that has been developed within the present study: from a file that describes a 2D mathematical function, BlindGraph prepares, in an automatic way, an enriched image of the graph as required by AudioTact®.

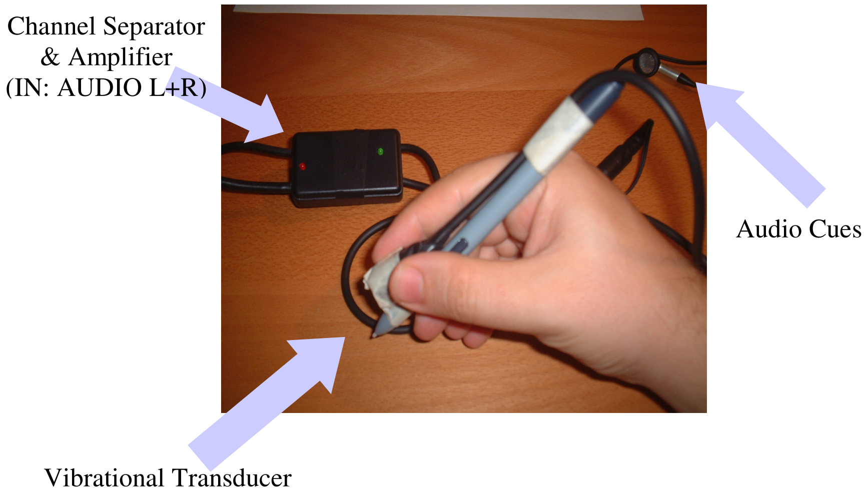

Fig. 2. AudioTact®: a picture of a pen with the vibro-audio device attached

Fig. 3. Experimentation of the AudioTact® device: a visually impaired user explores the virtual image using the left hand for spatial references and the right hand for scanning for aural and vibrational cues

At the moment BlindGraph assumes that the function is described by a Latex file but its architecture allows an easy extension to other formats. The file must define even the domain of the function.

During the exploration BlindGraph must constantly provide to the user some reference points, so that he can be oriented and perceive his own position in order to have an effective mental reconstruction of the image. When the cursor is near to the graph it is in charge of BlindGraph to send the right multimodal signals to AudioTact®.

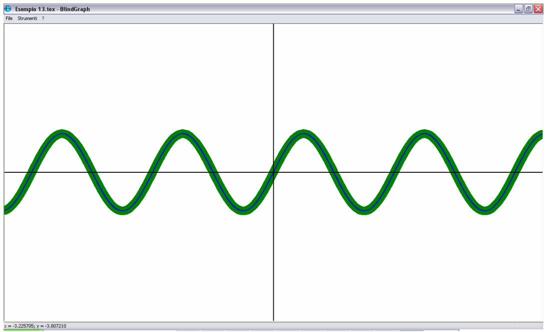

Fig. 4. Example of a graph generated by BlindGraph

In case of, during the exploration, the user catches a significant point, such as a maximum, he is informed by an appropriate message. To send a "speech message" to the user, BlindGraph interacts with Jaws®, one of the most popular screen readers. In this way the user can both perceive the graph and get the most significant points of the function.

Management of the Multimodal Stimulus. The following paragraph describes the rules used by BlindGraph to allow the graph exploration in conjunction with AudioTact™.

Aural stimuli. BlindGraph implements the sonification of the graph: an acoustic signal must be sent forth whose frequency is proportional to the ordinate. Obviously the relative value is meaningful and not the absolute one.

- when the user is to the least value of the codomain, the sound must have least frequency, independently from what the real value of the ordinate is;
- when the user is at the most value of the codomain, the sound must have the maximum frequency, independently from what the value of the ordinate is;
- only among 300 Hz and 3000 Hz the human ear perceives the increase of the frequencies in linear way and it is therefore only in this interval that the user succeeds in orienting in correct way; out of that interval a linear increase of the frequency would not be perceived as many linearly from the ear of the user and therefore a wrong information would be created to the ordinate of the position;
- the volume must also vary in proportion with the abscissa: increasing the abscissa, the volume increases;
- in case of the user incurs in one of the graph salient points, the user must be warns from a specific "speech message".

Haptic stimuli. Vibrational stimuli are used for confirming to the user that he is on the graph: when the user is on the graph, vibrational stimulus must be issued.

Different vibrational signals will be produced:

- signal of weak width in the case of decreasing function;
- signal of great width in the case of increasing function;
- signal of maximum width in the case of "speech message" from the application.

Besides the further information transmitted via the vibrational stimuli, they allow to the user to immediately perceive that he is in a significant point: when he is, for instance, near a minimum he perceives a vibrational stimulus of maximum width so he can break the exploration and listening to the speech message.

BlindGraph software architecture. As Fig. 5 shows, BlindGraph is made up of the following subcomponents:

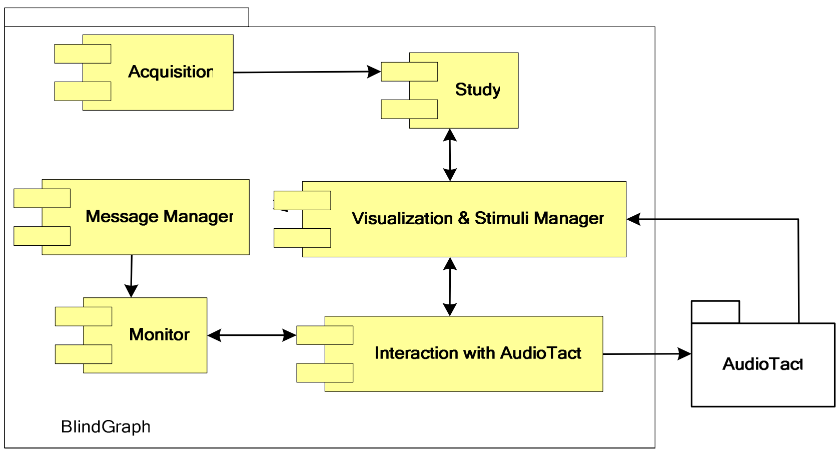

Fig. 5. BlindGraph software architecture

- Acquisition: it acquires the definition of the function from the file;
- Study: using the structure generated by the Acquisition subcomponent, it calculates the function by points and determines the significant points;
- Visualization & Stimuli Manager: displays the graph of the function and, depending on the user exploration, it stresses the Interaction with AudioTact® subcomponent and the Message Manager in case of a speech message must be sent, that is the user is near to a significant point;
- Interaction with AudioTact®: translates the inputs provided by the Visualization & Stimuli Manager subcomponent towards the signals for AudioTact®;
- Message Manager: translates the inputs provided by the Visualization & Stimuli Manager subcomponent towards speech messages;
- Monitor: both the audio signal for the exploration and the messages use the audio channel, so a monitor is required to manage the access to the same resource.

It is easy to understand that the Acquisition and the Study subcomponents are useful only to prepare the data for the Visualization & Stimuli Manager: if the data are not generated by a function but, for instance, from the historical value of a share, the system allow the exploration of the graph that represents the state of the share.

4 Experimentation and Results

Since BlindMath and TalkingMath had been successfully tested in the previous related degree thesis [6] [8], the experimentation presented in this paper, focused on BlindGraph and AudioTact®.

Table 1. Result of the practical tests

		User #1	User #2	User #3	User #4
Visual Disability		Partially sighted	Partially sighted	blind	blind
Mathematical knowledge		basic	basic	good	reasonable
Test 1	$y = x + 1$	10 min	7 min [2]	3 min	10 min
	$y = x^2$	4 min	7 min	6 min	failed [3]
	$y = \sin(x)$	7 min	12 min	4 min	5 min
Test 2	$y = x$	5 min	5 min		
	$y = x + 1$	5 min	3 min		
	$y = 3x + 5$	3 min	2 min		
	Differences	acknowledged	acknowledged		

The experimental sessions involved four blind operators of the Istituto dei Ciechi (Institute for Blind Persons) in Milano. All the users had been tested AudioTact® during previous experimental sessions validating other topics.

Two tests have been submitted to the user: the first one to verify if the user were able to recognize some common functions; the second one to verify if the user were able to recognize the differences between very similar function. The first test has been submitted to all the blind operators; the second one has been submitted only to two of the blind operators but only because the other two operators were very busy.

From the results of the tests, it seemed evident that the use of BlindGraph and AudioTact® results extremely effective in allowing the graph exploration and the success seems to be so more meaningful as greater the user mathematical knowledge is.

Further experimentation, with some visually impaired students of the Politecnico di Milano, are in progress.

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[2] After only 4 min, User #2 recognized that it was a straight line.

[3] User #4 easily recognized and explored the part of parable with positive abscissas, but for some reason not well understood he has not explored the part of function with negative abscissas.

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