Development of Software for Automatic Creation of Embossed Graphs

Comparison of Non-visual Data Presentation Methods and Development Up-to-date

Tetsuya Watanabe[1], Toshimitsu Yamaguchi[2], and Masaki Nakagawa[2]

[1] University of Niigata, Faculty of Engineering, Niigata, Japan
t2.nabe@eng.niigata-u.ac.jp
[2] Graduate School of University of Niigata, Niigata, Japan
{t.yamaguchi@eng, t12c114b@mail.cc}.niigata-u.ac.jp

Abstract. To investigate appropriate representation of numerical data to blind people, a user experiment was conducted. Its results have shown that embossed graphs give quicker and correct access to the data than braille and electronic tables. Based on this observation, we started developing software for creation of embossed graphs which can be operated by blind people. Up until now line graphs can be created with this software.

Keywords: Blind People, Tactile Graphs, Tabular Forms, Braille, Mathematics and Science

1 Introduction

When numerical data are presented in the form of a graph, the substance of the data (e.g. relative sizes, relative ratios, interpretation of trends, etc.) can be understood instantly. Reading graphs by touch takes longer than by sight, but even then, it should be possible to understand the substance of the data more quickly than when presented in tabular forms. Traditionally, many a graph have been transcribed into their tactile versions by volunteers and braille printing houses and many a research have been done to develop systems to do automatic transcription from the viewpoint of accessibility. But the advantages of tactile graphs over tabular forms have not been shown through experiments. Thus, we conducted an experiment, in which sets of numerical data were presented to blind participants in three ways: tabular forms on braille, tablular forms in electronic data, and embossed graphs and then correct rate and reaction times were compared among these methods.

Supposing tactile graphs have their advantages over tables, however, blind persons do not have any means to create graphs by themselves whereas it is easy for sighted people to create visual graphs using spreadsheet software. This situation prevent blind people who are engaged in intellectual work from dealing with and analyzing numerical data by themselves. Thus, the second objective of our research is to develop a system for automatic creation of tactile graphs from numerical data that can be operated by blind people.

2 Related Work

In Japan, as well as in other countries, a lot of efforts have been devoted to transcribe visual graphs into their tactile counterparts by volunteers and braille printing houses. However, the advantages of tactile graphs over tables have not been proven even in pedagogical area for special educational needs.

At the same time, many projects are under way to develop systems designed to make graphs accessible to blind users. These systems are classified as follows, depending on the method of presenting graphs and the method of inputting data.

There are three methods of presenting graphs: (1) conveying data via sound pitch and 2-dimensional acoustics [1-2], (2) vocalizing the form of the graph and individual data [2-3], and (3) making graphs tactile [4-5]. It is difficult to convey data accurately with the acoustic method, and moreover, since acoustics are volatile, information can easily be misheard. There are advantages in the method of vocalizing individual values as long as a screen reader is provided. By combining above two methods - using sound pitch and vocalizing values, drawbacks of those methods are alleviated [2]. To interpret trends in the data, however, the shape of the graph has to be imagined inside the user's head.

Tactile graphs, on the other hand, have the advantage that the general shape of the graph can be understood by touching it, but hardware is needed to generate tactile charts.

There are two methods of inputting data into graphs: (1) reading an electronic file of numerical data, and (2) scanning a printed graph. Although the former method is easier to use, in many cases only textbooks or other printed materials can be obtained. To address this, the method of scanning a graph, dividing it into text and graphics and re-pasting the braille-converted text into the graphics is being studied [4],[6].

We therefore decided to develop software that would easily allow data to be made tactile. This was based on an assumed situation in which users possess electronic data and make them tactile so that they can read the substance of the data by themselves. Research aimed at the same objective is also under way overseas [5]. There, the user is mainly assumed to be a sighted braille transcriber, and the software has a graphical interface. The output is an SVG-format image file, which is printed on capsule paper and passed through a heater to create a tactile graph.

In Japan, on the other hand, there are many users of embossed diagrams as tactile diagrams [7], and there is a good environment for people working in intellectual professions to use braille embossers in the workplace. Our development target, therefore, was software for automatic creation of embossed graphs operated by CUI (character user interface, which is easy for blind persons to use).

3 Experiment

3.1 Purpose

The purpose of the experiment is to investigate which representation method among braille tables, text files and embossed graphs suits blind people best for grasping the trend of the data quickly and correctly.

3.2 Stimuli

Twelve data sets which were comprised of a title, 20 *x* values, and 20 *y* values were prepared as stimuli: Three of them represented linear functions, another three inverse proportions, another three quadratic functions, and the remaining three non-correlated. Nine data sets were first calculated from the function they represented. Then, errors up to 10% of each datum were added to *y* values in order to imitate *observed* (not idealistic) data and to prevent the participants from easily calculating *y* values from the functions. Sizes and plus or minus of errors were determined based on the values calculated by the random function of Microsoft Excel. Non-correlated data were also produced using the random function. All data set had the same scopes of *x* and *y* values; 0<x<=10 and 0<y<120.

A braille table and an embossed graph used in the experiment are shown in Fig.1.

Fig. 1. A braille table (left) and an embossed graph (right) used in the experiment.

3.3 Participants

Participants were three blind universty students aging from 19 to 21 who use braille everyday. They have learned mathematics by means of braille textbooks including tactile graphs at a school for the blind. Two of them are majoring mathematics at universities.

3.4 Method

Four data sets representing four functions of the same condition (one of braille table, text file, and embossed graph) were presented to each participant all at once. Participants were then asked to select the function which was best represented by each data set and to explain the selection strategy or the reason for the selection. The experimentor measured the time required for the selection by a stopwatch. Participants were allowed to read the data sets in whichever order and how many times they liked. They were notified in advance that each data set had errors and differed from idealistc values.

There are six permutations to present three data sets. This time, three of them were assigned to three participants. The presenting order is shown in Table 1.

To read an text file, participants used their own personal computers (OS: Windows 7) with various screen readers (VDMW700, JAWS ver. 11, and PC-Talker 7).

Table 1. The order of presenting each condition differed among participants.

Participants	A	B	C
First	Embossed graph	Braille table	Text file
Second	Braille table	Text file	Braille table
Third	Text file	Embossed graph	Embossed graph

3.5 Results

Correct rates: Two out of three participants made perfectly correct answers in all conditions (Table 2). One participant mistook linear and quadratic functions for each other in the braille table and text file conditions. He commneted that these two were hard to distinguish from each other. Nevertheless, he made correct answers in the tactile graph condition in a shorter time.

Reaction times: All participants carried out the selection with shorter reaction times in the embossed graph condition than in the braille table and text file conditions (Table 3). This phenomenon is observed in all three presenting orders. Between the braille table and text file conditions, participants performed faster in the condition presented later.

Table 2. Correct numbers (numerators) out of questions (denominators).

Participants	A	B	C
Braille table	4/4	2/4	4/4
Text file	4/4	2/4	4/4
Embossed graph	4/4	4/4	4/4

Table 3. Reaction times (minutes:seconds).

Participants	A	B	C
Braille table	4:54	2:45	1:54
Text file	2:01	1:38	8:49
Embossed graph	2:00	0:40	0:26

Selection strategies: Features which were observable or had to be observed (calculated) to distinguish four functions differed in some points between tactile graphs and numerical data (braille table and text file), whereas they are the same between braille table and text file conditions (Table 4).

Table 4. Observed features of each function. Num. and Tac. are abbreviations for numerical data and tactile graph.

Functions	Features	Num.	Tac.
Linear and quadratic functions	General trend: As *x* grows larger, *y* grows larger.	*	*
	Ratio of *y* to *x* (calculated).	*	
	Changes of *y* values between neighboring two *x* values (calculated).	*	
	Plots approach *x* axis as *x* values become close to zero (quadratic function).		*
Inverse Proportion	General trend: As *x* grows larger, *y* grows smaller.	*	*
	Y values are very large when *x* values are close to zero.	*	*
	Decreasing rate of *y* values are very large when *x* values are close to zero.	*	
	Changes of *y* values between neighboring two *x* values (calculated).	*	
	Plots approach *x* axis as *x* values become larger.		*
Non-correlated	Changes of *y* values between neighboring two *x* values are unstable.	*	
	It felt as if there were multiple grahps or it were a circle.		*

3.6 Commnets

- Embossed graphs best suited for grasping the shapes of graphs. It can be achieved instantaneously.
- There were little difference between braille table and text file conditions: It was cumbersome to calculate from numerical data.
- Two participants who are majoring mathematics told that they were willing to use automatic tactile graph creation software when it is available.

3.7 Discussion

The experimental results have shown that tactile graphs are more appropriate for blind people to grasp the relationship between two corresponding variables quickly and correctly than printed or electronic tables. This is due to the difference in understanding strategies: To understand the relationship between *x* and *y* written in tables, the ratio of *y* to *x* and changes between neighboring *y* values must be calculated mentally: This calculation is tend to be hindered when the data include errors and deviated from the approximated functions: On the other hand, the shapes of graphs can be understood tactually within a few seconds.

In the future, advantages of tactile graphs should be proven statistically with more participants. Furthermore, disadvantages of them such as tactual limitation on precise reading of quantities should be explored (This would be compensated by using tables.).

4 Development of Software

4.1 System Requirements

After interviewing a researcher with visual impairment who works at a national research institute, we designed the system requirements as follows.

Accessibility by Blind Users: Software should be compatible with screen readers, enabling blind users to operate the system by themselves. CUI will be used in view of its ease of operation by voice. However, if requested by other users, we will also consider adopting GUI.

Types of Graphs: The first development target will be to create bar graphs (including histograms), line graphs and scatter plot graphs.

Operating System: Software should be operated via Linux console. We could consider a Windows environment depending on demand.

Braille Embosser: The targeted embosser is JTR, ESA721 ver.95, which can make embossed diagrams and is widely used in Japan. This model can print three sizes of dots – large (diameter 1.7mm), medium (1.5mm) and small (0.7mm). Plotting accuracy is 0.32mm horizontally and 0.35mm vertically.

Graph elements: Graph elements are images (axes, ticks, grid lines, and graph body) and text (title, axis labels, and unit labels). The user inputs these text elements in *kana* phonetic letters (Japanese alphabet), which are then displayed in braille.

Automated Text Control: Because braille takes up much space, (semi) automated text control functions are necessary. The functions we are planning to implement are showing a message to tell the user to shorten the title when it is too long and overflows the designated space, decreasing the digits of numerical labels, abbreviating the text of labels, and others.

4.2 Tactile Readability

Embossed graphs should be easy to understand by touch, in accordance with guidelines on the creation of tactile graphs and tactile charts in general [8-11]. The main points to bear in mind here are as follows.

Discriminability of Tactile Symbols: We have to use mutually discriminable surface, line and point symbols. Of these, the discriminability of line symbols is particularly important in graphs.

Of the types of dot made by ESA 721 embosser, the small dots are definitely discriminable from the other two sizes, but medium and large dots are harder to discriminate from each other. Therefore, it will only be possible to discriminate two different types with certainty by the type of dot. Changing the intervals between the dots makes various types of lines out of the same size of dots, but only two types can be discriminated with certainty. This will enable us to use four types of lines (two discriminated by different dot sizes and two by different dot intervals).

To make graph lines easily discriminable from grid lines, we intend to use dented dots (embossed from the front of the sheet) and make large enough space (around 3mm) between them by stopping grid lines before graph lines.

Searchability of Tactile Symbols: In line graphs, it has to be easy to search for point symbols from the graph lines. To this end, we either need to use tactually popping-out point symbols, or leave a large enough gap between graph lines and point symbols, or take both of these steps.

4.3 Flow of Operation

The following steps will be followed to create tactile graphs.

1. Read CSV data.
2. Input titles, labels and other text.
3. Set graph display parameters (type of graph, maximum values, minimum values, scale intervals, etc.).
4. Use a braille embosser to print graphs.

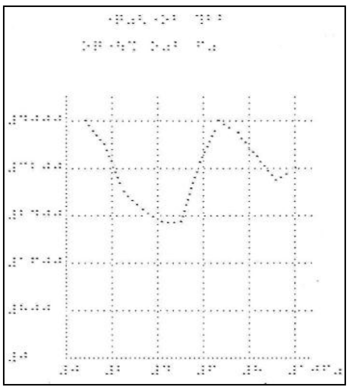

Fig. 2. A line graph created with our system.

4.4 Development Up-to-date

Up until now our system can create line graphs only (Fig. 2). Dented dots for grid lines and automated text control function are not implemented yet.

5 Future Works

Advantages and disadvantages of tactile graphs should be explored thoroughly with more participants.

The development of the software is still under way. When the software is completed, we will conduct experiments to verify its accessibility and tactile readability of graphs. On the accessibility of software, we will verify that blind users can operate the system with a screen reader, and will identify problems in operation. On the tactile readability of graphs, we will verify that lines can be followed and plot searches made accurately.

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