Exploration of Tactile Feedback in BI&A Dashboards

Erik Pescara
Karlsruhe Institute of Technology
erik.pescara@kit.edu

Xueying Yuan
Karlsruhe Institute of Technology
uxdxd@student.kit.edu

Maximilian Iberl
Karlsruhe Institute of Technology
maximilian.iberl@student.kit.edu

Alexander Klein
Karlsruhe Institute of Technology
klein@teco.edu

Ida Rockenbach
Karlsruhe Institute of Technology
uodtq@student.kit.edu

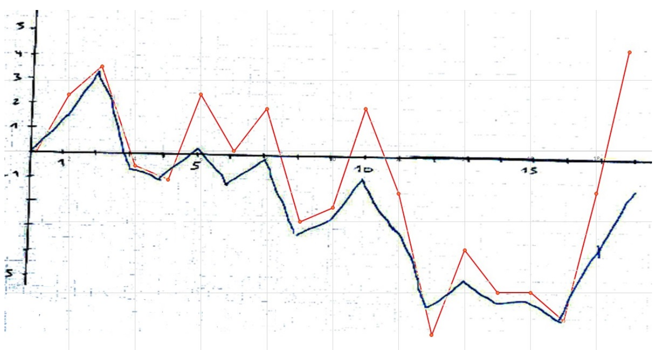

Figure 1: Graph drawn with only tactile feedback (black) compared to the original graph (red).

UbiComp/ISWC'17 Adjunct, September 11–15, 2017, Maui, HI, USA

ACM ISBN 978-1-4503-5190-4/17/09.
https://doi.org/10.1145/3123024.3124567

Abstract
This paper describes the development of a vibrotactile feedback system for the representation of piecewise linear graphs. It defines the basic idea of the system and describes the hardware and software in the background. It then shows how the vibration patterns, that are transmitted to the user via a wristband with two vibration motors, are calculated from the data points of the graph. The system is evaluated by a brief study with five participants. Based on this evaluation the paper suggests how the system can be improved, extended and applied in different fields of data representation.

Author Keywords
Haptic Interaction, Tactile Display, Vibrotactile Patterns, Tactile Graphs

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces - Haptic I/O

Introduction
Despite the relevance of human computer interaction in the working life of most employees, haptic feedback as a means of information display in computer based applications has been widely unexplored. Apart from the efforts made in sensory assistance devices for visually impaired

users, research in the field of haptic feedback has been mainly focused on applications for extreme or specific situations such as sports (for example a device for tactile vertical velocity perception for paragliding ([4]) and progress monitoring in a workout context([2])).

In this paper we explore and evaluate the use of vibrotactile cues as support of data representation in BI&A dashboards. We propose a simple application, designed for the haptic support of data visualization for piecewise linear graphs. Following the course of the graph, a wearable with two vibration motors continuously maps the changing slope using different vibration patterns. Fundamental research on the perception of vibration signals has shown that the skin has a high potential in perceiving tactile information ([1], [5]) and provides guidelines for the design of vibration patterns. The system is evaluated in a short study that examines the expressiveness of the vibrotacile representation.

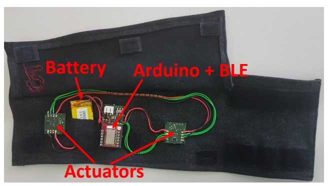

Figure 2: Tactile wristband with all components shown. The vibration actuators are placed facing the fabric, thus not seen in the picture.

Figure 3: Tactile wristband worn.

System Design

The general system requirement is wearability, which includes weight and size of the device. Accordingly, we opted for a wearable comprising two vibration motors attached to the fabric within 8 cm distance from each other and thus located on opposite sides of the wearable when closed (see Figure 2 and Figure 3). We used the technical system described by Diener et. al. (2017) with vibration actuators from Adafruit (Product ID 1201) and TI TLC5971 drivers to allow chaining actuators together with the SPI-like protocol of the drivers (see [6]). The central unit is the nRF51822 chip on the BLE Nano Board (16MHz, 256 KB Flash, 16KB RAM) [6]. The vibration motors are thin (2.7 mm) and leightweight (0.9 g) and produce vibration patterns at a comfortable and noticeable frequency of 121 Hz at 3.3V. The firmware development was done in Arduino [6].

Tactile Design

In order to represent the course of a piecewise linear graph, we agreed on vibrational frequency signals for each segment with the frequency depending on the slope of a segment. In order to facilitate the interpretation of the signals, positive gradients are represented by the upper vibration motor, negative gradients by the lower motor.

Each segment's frequency is calculated relatively to the segment with the biggest slope. The frequency for the biggest slope is set by the user as well as the simulation time for each segment.

Therefore, the frequency of the i-th segment simulation f_i is calculated with the following formula:

$$f_i = \frac{round(F\frac{s_i}{s_{max}})}{T}$$

F:	frequency for biggest gradient
T:	time to simulate a segment (in ms)
s_i:	slope at i-th segment
s_{max}:	maximum slope

For the study we set F to 20hz and the time to simulate one segment to 2000ms. Finally, f_i is sent to the wristband.

With the frequency, the wristband generates a vibration pattern, which is implemented in two different modes:

- Mode 1 uses different amounts of 100ms vibrations, while the pauses between vibrations decrease with the steepness of the slope.
- Mode 2 uses different amounts of vibrations of variable length, while the pauses between the vibrations is fixed at 50ms.

The slope is always indicated by one active actuator (blue), while the end of the slope is indicated by the two actuators vibrating simultaniously (dark blue), as seen in Figure 4.

Evaluation

For the evaluation of the system we invited five participants (two female, three male) between the age of 19 and 27 (mean age 22.2) to our lab.

After giving a general introduction to our system, a short demonstration of the tactile representation Mode 1 was given by providing the participant with the visual representation of three graphs and their tactile equivalents. This introduction phase was followed by the test phase in which the participants was asked to draw two graphs according to their tactile representation without seeing its visualization. These two steps were repeated for the tactile representation Mode 2. During the whole procedure, the participant was drawing with one hand wearing the wearable on the other arm in order to facilitate the task. Finally, the probands were asked to fill out a questionnaire.

Because for 11 of the 20 graphs we could not identify a coherence with the respective original graph, we analyzed the remaining nine for their quality. The reason for the ambiguity of the graphs seemed to be – according to the probands' statements – that they lost the attention on the graph and could not restart drawing it. From the 9 remaining graphs 5 were drawn with Mode 1 and 4 were drawn with Mode 2. Four of them were drawn by participant A, two by participant B another two by Participant C and one by participant D.

In the first step, we superimposed each of the graphs with the underlying data from the four test graphs for a qualitative impression of the results. For some of the drawings a surprisingly precise concordance can be observed (see

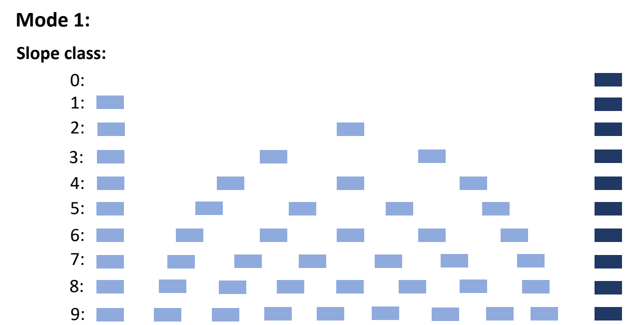

Figure 4: Mode 1 has vibrations of fixed length (100ms).

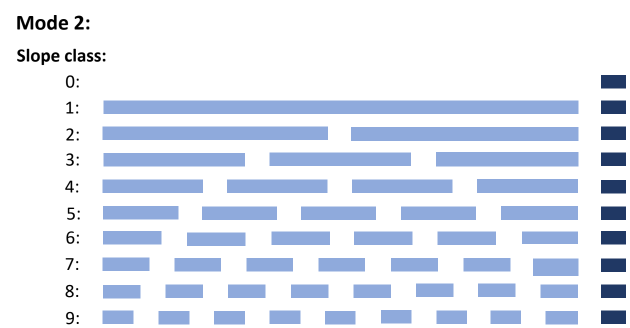

Figure 5: Mode 2 uses pauses of fixed lengths (50ms) and variable vibration lengths.

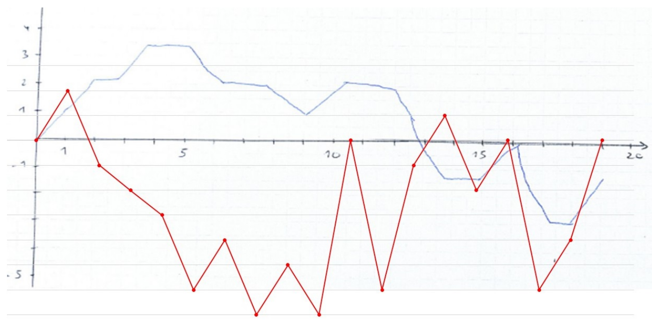

Figure 6: Example of a graph where the participant lost the attention.

figure 3) for others it is difficult to identify any connection between the drawing and the actual graph (see figure 6). A comparison of the results shows that the accuracy of the outcomes varies strongly between the probands. For a further analysis, we encoded the changing slope of the graph in four categories (1. changing signs, 2. decreasing absolute slope value, 3. increasing absolute slope value, 4. constant slope) and compared the values from the graphs with the results in the drawings. We were then able to determine whether the vibration patterns were interpreted correctly according to the four categories (see Table 1). This method emphasize the recognition and interpretation of the changes in the vibration signals in contrast to more mathematical methods that calculate the gap between the two graphs leading to distortions in the results.

Regarding the expressiveness of the different modes applied for the representation, the gathered data does not provide conclusive results, although Mode 2 had a slightly better result. Furthermore, no statement can be made about

Categories	Mode 1	Mode 2	Total
Changing Sign	82.5%	89.7%	85.7%
Decrease slope value	14.3%	28.6%	21.4%
Increase slope value	40%	55.5%	47.4%
Constant slope	80%	25%	56%
All Categories	71.7%	75.4%	73.4%

Table 1: Recognition rates of slope changes, for Mode 1, Mode 2 and both modes combined.

the occurrence of a training effect in the course of the study due to the small scope of the study.

A further evaluation of the answers from the questionnaire provides valuable information on the perception of the vibration patterns, suggestions for an amelioration of the system and ideas for other applications of the technology.

Concerning the perception, our participants agreed that the vibration of the wristband was pleasant and emphasized the importance of getting used to it while also being ambiguous about the further utility of the system. While only one participant said, that he would use the system for his own, the other four had ideas how the system might be suitable in different contexts, such as for blind people, communication or the transmission of stock market prices.

Apart from that, the participants also expressed suggestions for possible improvements of the system. Most of them agreed that the time span per each graph segment was too short. This might also correlate with the fact that they did not only have to perceive and classify the signal, but also to draw the right line at the same time. Another point of criticism was, that the interruptions between the signal patterns should be more distinct. Moreover, technical issues were seen as a matter of improvement as they criticized that the vibration intensity was too weak, especially from the lower vibration motor.

In sum, we observed that the drawings were in some cases surprisingly good. This was mostly dependent from the test person. We observed that the participants that had the best results with four (one participant) respectively two (two participants) relatively good drawings, stated in the questionnaire, that they already had experience with tactile interfaces by using gaming controllers. For this reason we suppose, that there might be a training effect. This question should be the object of further investigation. Probands could for example be confronted with the real graph afterwards, in order to gain experience.

Conclusion

We have seen, that – even in a short period of time – the vibration system can give a good impression of the course of a complex graph although overall the results are mixed. Especially the training effects during the usage of the system are worth a further scientific exploration. We believe that the utility of this system may increase in a world where big amounts of data have to be perceived and processed by the human mind. Our basic idea offers also a lot of possibilities for further extensions. On one hand it could be used to perceive data that is too complex for the two-dimensional on-screen presentation, on the other hand, it could intensify the impression of the data that is already on the screen. Especially the training effects during the usage of the system are worth a further scientific exploration. For future research it remains to be seen if tactile graph representation can be comparable to graph sonification (see [3]). A practical context, in which the system might be used, is the real time transmission of stock price trends in situations, where observing the graph on a screen is not possible, for example during a meeting or in the car. Also blind people may derive a benefit from the system, since acoustic graph representation systems are already in use. For future research it remains to be seen if tactile graph representation can be comparable to graph sonification.

Acknowledgements

This work was partially funded within the EU FP7 project Prosperity4All (grant agreement no. 610510). We thank the Karlsruhe School of Services (KSOS) and KPMG for their support.

REFERENCES

1. Stephen Brewster and Lorna M Brown. 2004. Tactons: structured tactile messages for non-visual information display. In *Proceedings of the fifth conference on Australasian user interface-Volume 28*. Australian Computer Society, Inc., 15–23.
2. Jessica R. Cauchard, Janette L. Cheng, Thomas Pietrzak, and James A. Landay. 2016. ActiVibe: Design and Evaluation of Vibrations for Progress Monitoring. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 3261–3271. DOI: http://dx.doi.org/10.1145/2858036.2858046
3. Wanda L. Diaz-Merced, Robert M. Candey, Nancy Brickhouse, Matthew Schneps, John C. Mannone, Stephen Brewster, and Katrien Kolenberg. 2011. Sonification of Astronomical Data. *Proceedings of the International Astronomical Union* 7, S285 (2011), 133âĂŞ136. DOI: http://dx.doi.org/10.1017/S1743921312000440
4. Erik Pescara, Michael Beigl, and Matthias Budde. 2016. RüttelFlug: a wrist-worn sensing device for tactile vertical velocity perception in 3d-space. In *Proceedings*

of the 2016 ACM International Symposium on Wearable Computers. ACM, 172–175.

5. Hong Tan, Robert Gray, J Jay Young, and Ryan Taylor. 2003. A haptic back display for attentional and directional cueing. (2003).

6. Matthias Budde Erik Pescara Vincent Diener, Michael Beigl. VibrationCap: Studying the Vibration Sensitivity of the Human Head with an Unobtrusive Wearable Tactile Display. (*To be published in ISWC'17*).