Parameters for Evaluating Tactile Structures Produced Using Ink-jet

Don McCallum, Jonathan Rowell, and Snir Dinar, Anglia Polytechnic University, Cambridge, England

Abstract

Ink-jet is a robust method for the production of tactile maps and diagrams for people with visual impairment and its use is likely to proliferate. As with visual images, tactile map features can be evaluated by their engineering properties such as mechanical robustness, longevity and precision. However, the quality of the tactile structure can also be evaluated on the basis of psychophysical parameters that can be used to measure the perceptual qualities of a tactile map. The classical retinal variables of shape, size, value, orientation, hue and texture are re-worked to come up with a set of haptic *variables; size, shape, elevation, texture, line profile and symbol location, by which the usefulness of a tactile map can be gauged. Examples of each of these variables have been manufactured and samples are presented for demonstration and critique. By better understanding the haptic processes it is intended that the amount of information that can be conveyed to a tactile map reader can be maximised, while the engineering resource of the map and its manufacture can be minimised.*

Background

There are many methods of measuring the quality of visual images. An image can be measured by the saturation of its colours,[1] the range of the colour gamut,[2] the resolution and so on. Some of these properties can be assessed psychophysically, often by simply asking for peoples opinions or preferences about images,[3] and in other scenarios they can be assessed purely quantitatively.[4]

Furthermore robustness and longevity are also a measure of the quality of graphics. This includes; lightfastness, bleed, consistency, stability, fading and scratch resistance, which all contribute to the usefulness of a printed image.

Aspects of design can also influence the effectiveness of graphics. Authors use bold, italic and underline to alter typefaces for various emphases. Layout and clarity of images may vary depending on the intended use. For example colours, fonts and presentation in commercial advertising will be different to those used in legal documents. The size of images needs to be considered as to who is using the image in what space; many will be familiar with the scenario of an optician's surgery to assess ability to read text at a given distance. Protocols are generally followed to help a viewer's uptake of information; take the convention of Latin based text that flows left to right and top to bottom. Add to these immeasurable artistic factors, a consequence of the intuitiveness of design and we begin to realise why sometimes one image just *looks good* while another may not.

Many people are familiar with Braille, a system of raised dots used to represent text characters for people with visual impairment to access through touch. Fewer are aware of tactile graphics; diagrams where not only text but also other graphical elements such as point symbols, lines and areas are raised. It has been shown that tactile diagrams are useful for providing all kinds of spatial information for people with visual impairment, aiding mobility, education, employment and independent travel.[5]

Making an assessment of image quality is a more complex process when dealing with tactile graphics, largely because users only use their fingertips to gather information. Tactile reading is slower and more prone to error than reading by sight, partially due to the sensitivity of touch compared to vision. As usually no more than two points can be accessed at a given moment, overviews are difficult to ascertain and a reader relies more on memory. Though several sets of guidelines exist that encourage good practice in the design and production of tactile diagrams[6,7] these have not considered more recent manufacturing technologies such as ink-jet, are far from comprehensive and are generally not grounded in psychological or other map design research. Ink-jet has shown itself to be a technology adept at producing a range of tactile features. A multi-pass ink-jet process is able to build structures on a substrate that are elevated sufficiently for tactile exploration.[8] It enables modifications and variations in the dimensions and structure of features in ways that existing technologies have previously found difficult.

The remainder of the paper provides an analysis of tactile image quality based on a set of tactile parameters. These parameters are derived from the fundamentals of psychophysics, neurological studies, earlier tactile design guidelines, and experimental data regarding symbol discrimination, identification and preference.

Haptic Psychophysics

Touch and the study of touch are referred to as *haptics*. There are two aspects to haptics; *tactile* which is primarily concerned with feel and the affect stimuli have on enervating receptors in the fingertip, and *kinesthetic* which regards the muscular and skeletal framework in which touch occurs. Tactile psychophysics research provides data on functions such as roughness perception,[9] two point discrimination[10] and detection thresholds.[11] Neurological studies have recently been able to chart the complex set of nerves in the finger and identify the roles and responses of different nerve types.[12]

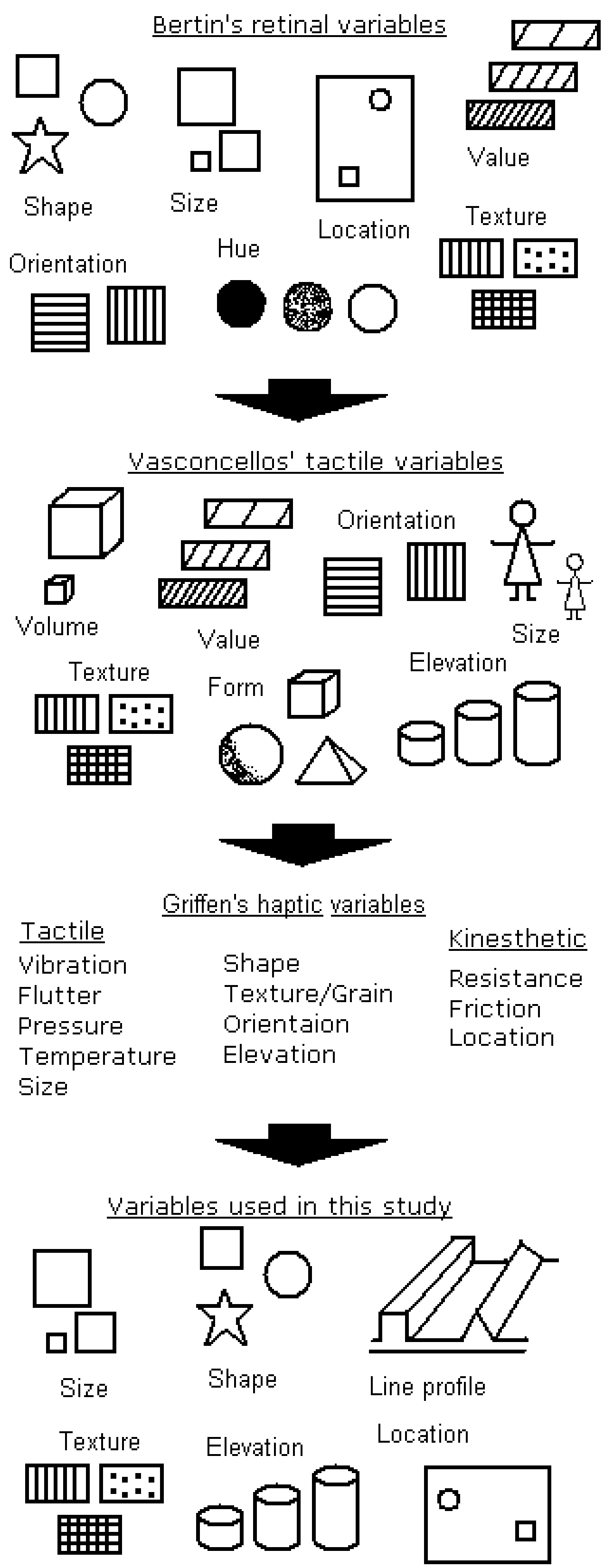

Figure 1. The evolution of a set of haptic variables

Psychophysical and neurological data is useful and can be used as a cue or broad reference for tactile structures, but to try and design more effective tactile structures on the basis of this data alone would be overly complex. The receptors of vision enervating the eye are scattered pseudo-randomly throughout the retina, yet we see clear, distinct shapes and colours. This indicates the high level of processing undertaken by the brain in helping to form cognitive images from the original nervous stimuli. Similar complexity arises in touch; a change in magnitude of stimuli, rather than absolute magnitude, is more important for triggering sensation in some haptic nerves.[12]

Tactile Cartography

Though our proposed methodology of using tactile variables as the basis for evaluating the effectiveness of design could apply equally to all diagrams, in this paper we restrict ourselves to maps as a distinct group of graphics for representing useful spatial information. For cartographers all map elements (graphic marks used to represent geographical features) are classified as point, line or area symbols. Bertin[13] proposed a set of retinal variables; *shape, size, value, orientation, hue, texture* and *location*, as ways by which graphic marks could be differentiated.

Vasconcellous[14] attempted to translate these visual variables into their tactile equivalents. These were developed further by Griffen.[15] While we agree with Griffin that volume as a composite variable comprising size, shape and elevation should not be included, and that value a print industry parameter in the tactile sense is very much part of, texture, this project has argued for including *line profile* in any set of tactile variables,[16] to take account of complex variations in three-dimensional form.

To simplify this study further, several other Griffin variables are disregarded. A result of the many and varied ways tactile maps are oriented during reading, it is not possible to use orientation as a characteristic to define between different map elements. Because we are only concerned with static maps rather than more complex dynamic representations of space in this study, vibration and flutter are not relevant parameters in our evaluation. We also consider temperature to be ambient, and omit pressure and the kinesthetic variables of friction and resistance as users of static maps make compensatory adjustments for these factors.

Haptic Variables

As a consequence of the complexity of ink-jet, a large number of input and output parameters and performance indicators exist. The subsequent discussion concentrates on *design variables*, those that can be altered by modifying the design in software, and *structural variables*. Others, which cannot be altered merely by software, but are dependent on the modification of other material or machine parameters, are not emphasized. Though the set of haptic variables proposed in Figure 1 might not be absolutely definitive, they can be readily manipulated using ink-jet and their performance can be measured. The following sections briefly consider each of the haptic variables

Size

In order to fit adequate information on a tactile map it is often desirable to make symbols small (*small* might mean fitting under a finger pad). Experiments showed that point symbols are not readily identified where primary length was below about 4 mm.[17] Weber fractions, the percentage difference in stimulus attribute required for said difference to be noticed, are commonly used psychophysical tools; the higher the fraction the more readily difference is perceived.

A size constancy experiment was conducted to understand what determines equivalence of size between differently shaped point symbols. Though results have not been published early indications suggest that symbol area is the main factor upon which judgment about similar sizes are made tactually.

Shape

A survey found over 500 different point symbols and 100 different line types used in practice and research. Over had been used as well. Discrimination studies[18] showed that based on shape (all other variables held approximately the same), a useful set of point symbols might only contain 12 elements, and a highly discriminable set of line symbols might only contain 4 types.

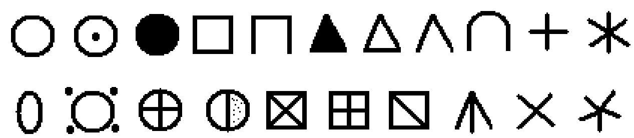

Figure 2. Top row is a set of highly discriminable point symbols; those in the bottom row are often confused.

Whereas the other haptic variables have some ordinal (measurable) aspect, shape is not readily quantified. Thus it is difficult to give numerical values to the differences in shape between symbols. The term shape is used to describe what is formed when representing a jagged coastal outline and a plain circle representing a city.

Location

The location of a symbol can help to discriminate it from surrounding symbols. Meaning can vary depending where on a map a symbol is placed and in what context. The layout of symbols should be simple and unambiguous, while closely representing the original image.

An important aspect of location is proximity. Symbols too close to each other can be difficult to differentiate. As shown in Figure 3, visual and tactile separation requirements are not always be the same.

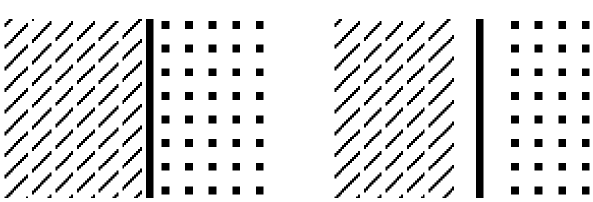

Figure 3. Proximity: The vertical line on the left will be difficult to notice tactually, whereas the one on the right will be readily identified.

Using ink-jet to produce tactile maps, the ability to change size, shape and location in relatively small but easily identifiable ways involves only minimal adjustments to the graphics file.

Line Profile

Until recently evaluating variations in the third dimension has not attracted the attention that other variables have. Here we refer specifically to line profile, which is a combination of design and structural variables. While a fair degree of control over line profile can be exercised via the design (e.g. by making the subsequent bitmaps of the later print passes smaller, conical and triangular profiles are created), the flow and coalescence of inks on substrates mean there is a smooth/domed characteristic to the structures generated. A number of technologies have shown accurate, repeatable control and the ability to construct vertical walls and complex three-dimensional structures with ink-jet.[19]

Pilot studies have shown that basic differences in line profile (square, round and triangular) are discriminable and can be used as a distinguishing feature between lines. Line profile is a difficult variable to quantify. While some aspects of line profile are measurable (Figure 4), others are not. Line profile also encompasses complex shapes in the third dimension.

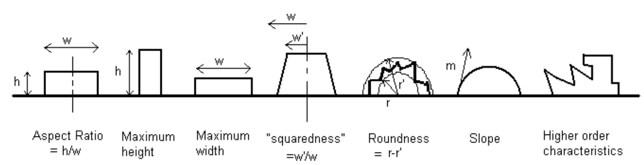

Figure 4. Some aspects of line profile.

Elevation

The elevation of raised print structures impacts on the way tactile symbols are accessed. While guidelines recommend tactile features be around 0.5 mm (500 microns), experiments have shown some users frequently identify symbols as low as 10 microns. Performance increases with increasing elevation, though acceptable performance levels were reached at 100 microns and plateau at about 200 microns.[17] It is also possible to speculate that symbols over a certain height hinder tactile map reading.

Texture

Texture is a complex variable. It can be described as possessing attributes of grain, orientation, value, density, arrangement, spacing and randomness. Texture comprises repeating elements that may all vary in size, shape, separation, line profile and elevation. Thus it demonstrates that overlap between variables can exist–differences in line profile can contribute to differences in texture. The perception of texture is not easily quantifiable; best evaluations could be made on the basis of a multi-axis parameter with soft/harsh, thin/thick, relief and hardness components all acting as a measure.[20]

Roughness is known to be an important parameter for texture discrimination. With linear based textures, increasing groove width and decreasing land width are known to increase roughness. Unpublished experiments have shown that with dot-based textures, elevation is more dominant in roughness perception over dot spacing or dot diameter. The background texture of substrates has been found to have an affect of tactile map reading experiences. Not only is performance in map reading tasks superior with rougher, papery substrates, they are also preferred by users.[21]

Overview

An exploration of tactile structures produced using ink-jet has helped us to identify a set of variables that can be used to assess the quality of tactile maps. By understanding these quality parameters, engineers producing tactile features defined by the variables can ensure that they are grounded in psychophysical research and provide optimal access through touch. An understanding of basic design will allow engineers to work better with tactile cartographers, who in turn need to develop an understanding of structural requirements,. Such cross-fertilization should result in better tactile maps the best outcome for users.

The possibility of introducing more variables must also be evaluated. Though hardness and compliance have been investigated in psychophysical literature[22] they have not been considered as haptic variables. By varying inks and ultra-violet curing systems, ink-jet posses the capability to make solid structures that vary in hardness, from soft and rubbery to hard and rigid. Such differences could be very useful. Non-haptic parameters such as the adhesion of jetted structures to substrates and their resistance to deformation could also contribute to the overall image quality.

Work on the psychophysical parameters of tactile structures is adding to significant amounts of research already documented. However existing work has typically concentrated on discrete symbols and single parameters. There is much to be gained from investigating symbols in combination, and where two or more variables occur. In one experiment using tactile maps, elevation *and* texture of symbols were varied. Results showed that people perform better at low elevations if symbols are roughly textured.[17]

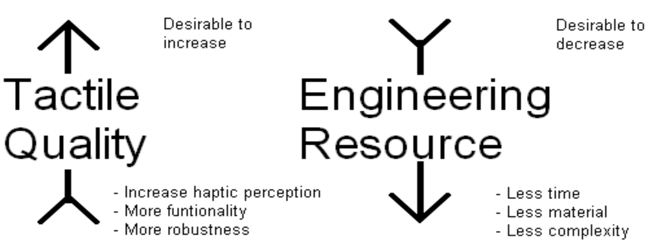

Figure 5. A design paradigm.

Elevation is a resource hungry variable. Increasing elevation usually requires a greater number of print passes (adding time) or more print-heads (increasing complexity and capital) and uses more material. Adding texture to a symbol allows a decrease in elevation and requires only a few minutes to alter the graphics file.

Knowledge of tactile variables is not only an advantage in ensuring quality of output; it can also help to optimize the digital fabrication process. Considerable improvements to tactile maps can be made by adhering to good design and need not always involve costly engineering developments.

Acknowledgments

The Engineering and Physical Sciences Research Council of the UK funded this research. (Grant number GR/R94480/01.)

References

1. T. Watanabe, Y. Akimoto, and Y. Hoshino, Image quality improvement by rescaling of color saturation, Proc. IS&T's NIP 20, pp. 416-419. (2004).
2. M. Inui, T. Hirokawa, Y. Azuma, and J. Tajima, Color gamut of SOCS and its comparison to pointers gamut, Proc. IS&T's NIP20, pp. 410-415. (2004).
3. Y. Bang, Z. Pizlo, J. P. Allebach, and N. Burningham, Discrimination Based Banding Assessment, Proc. IS&T's NIP 19, pp. 745-750. (2003).
4. C.-H. Liu, C.-J. Chen, Mon-Da Yang, and Y.-J. Li, Method of measuring resolution for printer, Proc. IS&T's NIP19, pp. 755-757. (2003).
5. S. Ungar, M. Blades, and C. Spencer, "The role of tactile maps in mobility training", B.J. Visual. Imp., 11, (1993).
6. E. A. Gardiner and C. Perkins, Best practice guidelines for the design, production and presentation of vacuum formed maps. http://www.sed.manchester.ac.uk/geography/research/tactileguidelines/ (2003).
7. P. K. Edman, Tactile Graphics (American Foundation for the Blind, New York, USA, 1992).
8. D. McCallum, J. Rowell, and S. Ungar, The use of ink-jet to produce tactile maps, Proc. IS&T's NIP 19, pp. 891-895. (2003).
9. S. J. Lederman, "Tactile roughness of grooved surfaces: The touching process and effects of macro and microsurface structure", Percept Psychophys, 16, 2 (1974).
10. R. Cholewiak and A. Collins, Sensory and physiological bases of touch *in The Psychology of Touch* (Lawrence Erlbaum & Ass, Hillsdale, New Jersey, USA, 1991).
11. R. H. LaMotte and J. Whitehouse, "Tactile detection of a dot on a smooth surface: peripheral neural events", J. Neurosci, 56, 4 (1986).
12. K. O. Johnson "The roles and functions of cutaneous mechanoreceptors", Curr. Opin. Neurobiol., 11, (2001).
13. J. Bertin, Semiology of Graphics: Diagrams, Networks, Maps (University of Wisconsin Press, Madison, WI, USA, 1983).
14. R. Vasconcellos, Knowing the Amazon through tactile maps, Proc. 15th Conf. of ICA, (1992).
15. A. L. Griffin, "Feeling it out: the use of haptic visualization for exploratory geographic visualization", Cartog. Pers., 39, (2002).
16. S. Dinar, J. Rowell, and D. McCallum, The uniqueness of symbol profile as a design variable intactile cartography, Proc. ICC, A Coruna, Spain, (2005).
17. S. Jehoel, S. Dinar, D. McCallum, J. Rowell, and S. Ungar, A scientific approach to tactile map design: minimum elevation of tactile map symbols, Proc. ICC, A Coruna, Spain, (2005).
18. S. Jehoel, S. Ungar, D. McCallum, and J. Rowell, Discriminability of map symbols in tactile cartography, Proc. AAG, Dever, Co, USA, (2005).
19. X. Zhao, J. R. G. Evans, and M. J. Edirisinghe, "Direct ink-jet printing of vertical walls", J. Am. Ceram. Soc., 85, 8 (2002).
20. D. Picard, C. Dacremont, D. Velentin, and A. Giboreau, "Perceptual dimensions of tactile features", Acta Psychol, 114, 2 (2003).
21. S. Jehoel, S. Ungar, D. McCallum, and J. Rowell, An evaluation of substrates for tactile displays: scanning speed and user preferences, Proc. Eurohaptics, Munich, Germany, (2004).

22. M. A. Srinivasan and R. H. LaMotte, "Tactual Discrimination of Softness", J. Neurophysiol, 73, 1 (1995).

Author Biography

Don McCallum graduated from the Australian National University in 1996 with a BE (Hons) in Electromechanical Systems Engineering. He spent 3 years working in the West Australian mining industry developing advanced ceramics, wear resistant metals and welding processes. He moved to England in 1999 to take a position researching and developing tactile maps and ink-jet processes. This has become the topic of Don's PhD research, currently in its final year.