THE UNIQUENESS OF SYMBOL PROFILE AS A DESIGN VARIABLE IN TACTILE CARTOGRAPHY

Snir Dinar, Jonathan Rowell & Don McCallum

Tactile Inkjet Mapping Project, Department of Geography, Anglia Polytechnic University, East Road, Cambridge, CB1 1PT, UK. Email s.dinar@apu.ac.uk or j.rowell@apu.ac.uk

This paper summarises the conceptual development of a set of graphic variables for tactile cartography, emphasising the unique qualities of symbol profile, particularly lines, within the context of the Tactile Inkjet Mapping Project. The development of a unique printing method using new inkjet technology allows unprecedented control over tactile features. For the first time it is possible to print a range of 3-dimensional shapes direct from a computer. A description of the printing process is provided. Evaluating tactile variables according to principles outlined by Bertin, line profile appears to correspond closely with colour (hue) in visual cartography, and has the potential to be used qualitatively to represent nominal (categorical) spatial data. This paper explains an innovative method used to achieve cross-sectional profiles, their relevance within the context of a revision of Vasconcellos tactual variables and ways tactile line profiles could be deployed to provide visually impaired people with supplementary map information.

1. INTRODUCTION

Increasing amounts of information nowadays is provided graphically, especially non-linear information (i.e. diagrams, graphs and maps) which is difficult to describe by text alone. Information is crucial to education, orientation and routine daily activities. While sighted people can access this information easily through many mediums, visually impaired people only have access to limited amounts of it after it has been converted into other formats.. Available formats include audio-tapes, tactile maps and more recently computer software with speech and multimodal electronic devices (Jacobson, 2002) [1]. Audio-tapes serve a useful purpose for transcribing textual information, however they are largely considered inadequate for describing spatial information. On the other hand multimodal devices can potentially provide access to spatial information through haptic and auditory interfaces, making the information more accessible and easier to use.(Oviett, 1997) [2] However, these newer technologies are still in their infancy, relatively expensive and potentially can only be deployed in places where the technology is situated. Tactile maps in contrast, could be considered more versatile. They have both a long history of [quote] and there are multiple ways of manufacturing tactile diagrams. Mixed-media, microcapsule paper and thermoform are the most common methods (Rowell and Ungar, 2003) [3]. Assessment of the advantages and disadvantages of these production methods have already been made (Horsfall, 1997) [4] however, an outline of the drawbacks in using these would include:

a. Low adhesion.
b. Time consuming.
c. Multi-phase preparation
d. Not suitable for multiple or outdoor use.

Significant improvements in the accuracy, repeatability, speed and cost of inkjet printheads over the last decade have led to a rapid growth in the number of areas in which this technology can be applied. In particular, using the technology to produce tactile maps and diagrams could prove advantageous over parallel. In this paper we present one aspect of that development, how to produce cross sectional profiles using an innovative method with the new tactile inkjet technology. The relevance of profile from a tactile variable perspective is discussed and potential ways of incorporating profile within the context of tactile map design are suggested.

2. MAPPING VISUAL TO TACTILE VARIABLES

Vasconcellos (1991; 1993) [5, 6] was first to identify the value of applying principles proposed by Bertin (1977) [7] in his Graphic Semiology, to developing a tactual graphic language. In most cases Vasconcellos thought it was possible to make a direct translation of visual variables into their tactual equivalents simply by adding a third dimension. Thus elevation (height) was used to create a new set of graphic variables, volume, size, value, texture/grain, form and orientation that could be touched. How the tactual variable set maps onto levels of measurement is not made explicit. Hence we have to assume that the degree of correspondence between Vasconcellos' tactual variables and Bertin's retinal variables is such that the syntactic rules for use are the same (MacEachren, 1995) [8].

There does however appear to be some misunderstanding in MacEachren's (1995) interpretation of Vasconcellos. Although in her graphic colour seems to map directly onto elevation as its tactile equivalent, it is not possible to uphold such substitution, as a correspondence does not exist. Elevation is not a substitute but an alternative tactual variable. Here we must distinguish between elevation that makes print raised and differences in height. In the latter case elevation works as an ordinal variable, higher elevations represent greater intensities that maps easily onto mental image constructions of quantitative values. For example map marks that are elevated higher than those that surround it can be used to highlight prominent features. In her text Vasconcellos recommends that texture be used in place of colour as it can be utilized equally well to represent qualitative, ordinal and numerical data.

Just as many authors in visual cartography have offered critiques of the dogmatic nature of Bertin's syntactics (MacEachren, 1995), and argued that his typology is incomplete (Morrison, 1974; Caivano, 1990) [9, 10], Griffin (2002) [11] has made similar remarks about Vasconcellos, claiming that the simplistic nature of translating Bertin's visual variables into tactile form fails to take account of variables that can only be perceived haptically. Here she refers to temperature, pressure and kinaesthetic variables such as resistance and kinaesthetic location. The fact that these extra haptic variables work more efficiently in dynamic situations, mean they are more relevant to new technologies, particularly multi-modal interfaces that often include amongst other tools a vibrating mouse. Though traditional tactile maps are increasingly seen as redundant in the face of developing technology as they are considered static, unintelligent, inflexible and cannot be manipulated to change scale or perspective (Jacobson, 2002), they still remain valuable independently, or as one element in a multifaceted approach to addressing the spatial needs of visually impaired people. Hence the tactual variables defined by Vasconcellos still apply in the context of use with static tactile maps. They could however benefit from some revision.

2.1 Revision of tactual variables

Several aspects of the Vasconcellos translation of visual to tactual variables remain unclear. It is quite difficult for example to see how geographic position in the plane equates with volume. It is not certain whether the variable is set to mean volume emphasizing, to be used with symbols that represent the vertical dimension of a spatial phenomenon by location (Robinson, 1995) [12], for example in visual mapping the use of contour shading. If this is the case then volume becomes a factor of symbol categorization and is not a graphic variable at all, tactual or otherwise, unless volume is understood as a composite variable comprising shape, size and elevation, in which case it is redundant being a combination of these other factors.

There is also some lack of clarity about texture/grain. Vasconcellos fails to allude to how compared with vision texture can be perceived differently through touch. In addition to a direct visual tactual correspondence between large textures that involve differences that can be seen and felt, referred to by many cartographers as pattern, it is also possible to create textures involving differences in the grain at microscopic levels. While a different surface finish, as we call it, can be identified by touch, to all intents and purposes they often look the same and are therefore not visually discriminable.

Most important of all Vasconcellos does not define factors that help describe differences in shape between two-dimensional and three-dimensional forms in their totality. Once a symbol becomes raised it can be viewed as an elevated 2D plan or a 3D structure from a cross sectional perspective, and all its dimensions need to be explained. It is for this reason that we propose to make a distinction in form between the dimensions of the plan view and those that occur in cross section. It is also important to distinguish between a two dimensional form that is simply raised of the page by virtue of providing it with elevation, and more complex three-dimensional shapes. Thus it is our contention that another tactual variable should be added to the list proposed by Vasconcellos to account for defining differences in shape in three dimensions as well as two. The new variable is called profile.

Like elevation profile is solely tactile, though it is very much a secondary rather than a primary variable as it is composite and comprises size, height and form. However it does so in unique configurations as a consequence of the occurrence of these variables in the third dimension. Therefore any description of profile should also include to greater or lesser degrees factors such as (i) slope, (ii) curvature and (iii) complexity. Assuming of course that technology exists to allow us potential control over form in three-dimensions, the following elements need to be defined. The angle or gradient of slope, the degree of curvature, and the individual complexities of profile must all be described. Is the profile symmetrical or asymmetrical? Is it plain, simple or does it consist of notches, steps or other graphic nuances that make any description of a profiles shape more complicated. This of course begs the question how these differences can be manipulated given our current knowledge of how touch works to create unique profiles, and how these might be utilized in a cartographic context/scenario to improve tactual discrimination between map elements. What features might profiles best be employed in representing?

Tentatively evaluating profile as a tactile variable according to principles outlined by Bertin, it appears to correspond closely with colour (hue) in visual cartography, and has the potential to be used qualitatively to represent nominal (categorical) spatial data, particularly if profile is used to define between lines or symbols that are primarily comprised of lines, for example outline points. However such substitution should be approached with caution. With the understandable caveat that some colours are more prominent, sighted users are still unlikely to make quantitative judgements based on their differences, however the sharpness of profile can be considered to indicate intensity and imbue a feature they are being used to represent with unintended meaning. Although there is only a partial visual tactual equivalence, this can potentially be exploited to a tactile map user’s advantage, if used expeditiously.

In our revision of tactile graphic variables we would lose volume, it either being a function of geographic location rather than directly graphical, or it arises from a combination of our other variables; slope/profile, form, size and elevation.

Furthermore though no explicit reference to it is made in the paper, in future it might be possible to examine how profile can be used to build texture structures that feel quite different to the current palette of area symbols tactile cartographers use, for example introducing textures that have an element of directionality to them.

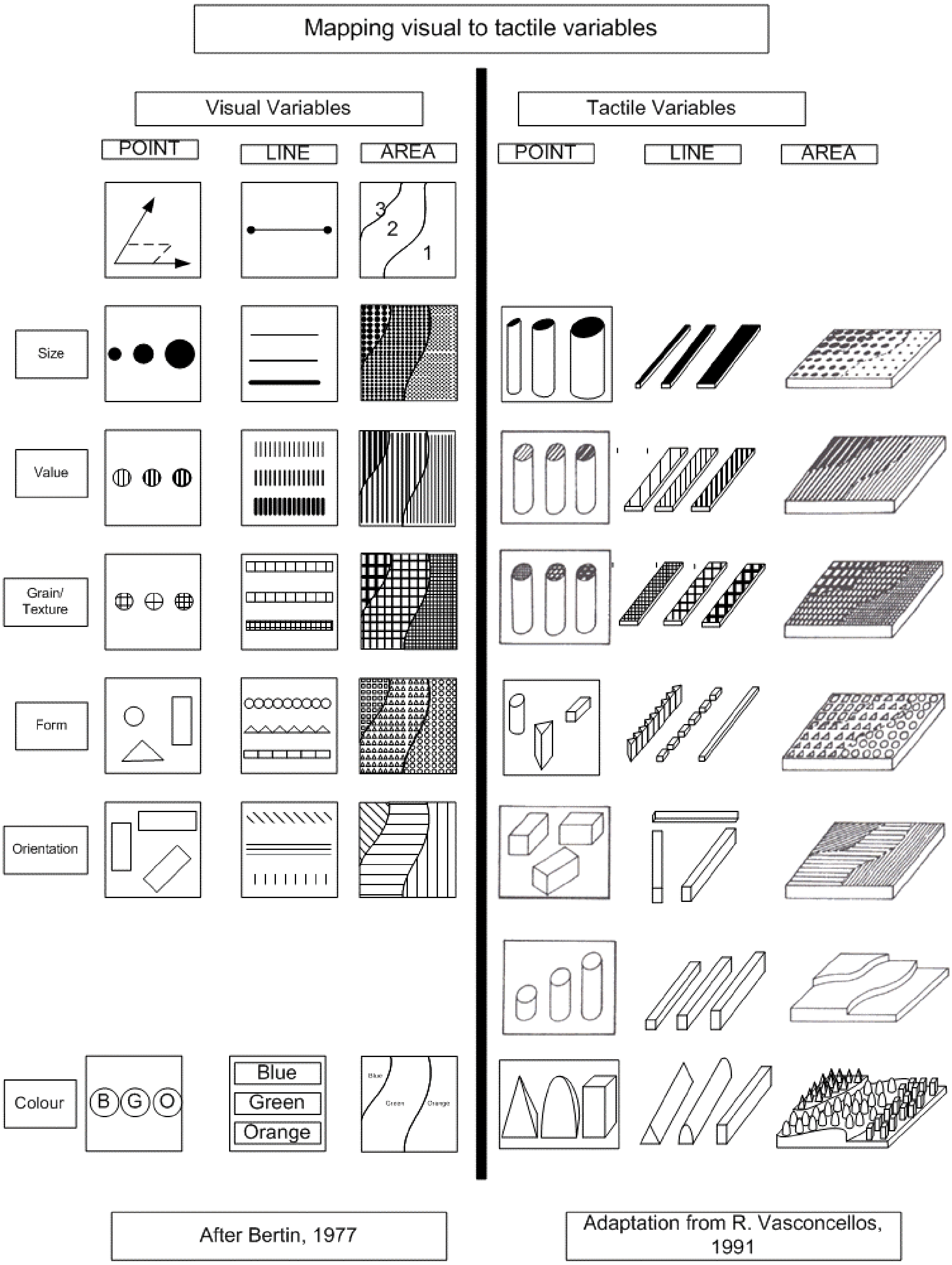

Figure 1: Mapping visual to tactile variable

3. CONTROL OVER LINE-PROFILES

3.1 The APU Machine

The research and development printer at the centre of the Tactile Inkjet Mapping Project (TIMP) research programme contains four main areas:

- A Xaar XJ500 piezo-electric binary printhead and ink plumbing system;
- A curing system using ultraviolet light;
- A printing algorithm controlling the actuators' movement in 3 axes.
- Image analysis and information feeding algorithm.

The machine is capable of printing any size up to A3 (297mm by 420mm). Common substrate types used include: PVC, polystyrene, acetate, foam boards, aluminium and High Impact Polystyrene (HIP). Adhesion of the features to the substrate can vary depending on the substrate type

The tactile output is achieved by printing multiple layers of polymer ink, one on top of the other, forming an elevated structure. In between each printed layer of ink the substrate is exposed to ultraviolet light that causes a partial solidification of the ink, preparing the substrate and ink for the next printed layer.

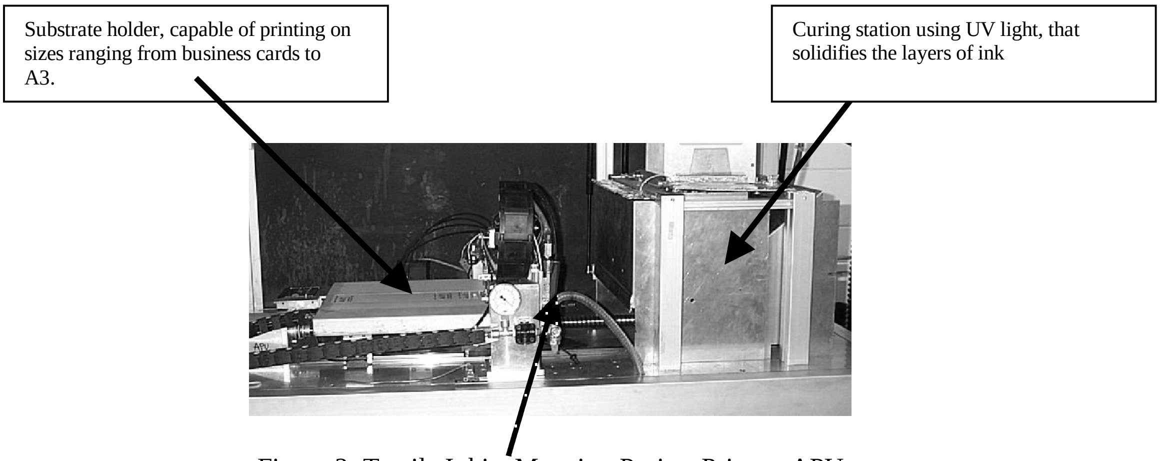

Figure 2: Tactile Inkjet Mapping Project Printer, APU

3.2 Background

By default printing a line using the process described, results in a dome shaped (see figure 6b) cross-sectional profile.(McCallum 2005) [13] This is due to the surface tension of ink interacting with the surface energy of the substrate (Podhajny 2004) [14]. Our challenge was therefore to introduce a degree of control in the process allowing us to achieve other cross sectional profiles such as squares and triangles. Technologies from neighbouring fields (Rapid Prototyping) have tackled this problem by introducing a 'second process'. Supporting gel and a shearing cutter are two examples. The gel works alongside the main ink being printed by supporting the structure helping it to form the desired edge. Upon curing and complete solidification of the ink the gel is removed leaving the structure intact. The shearing cutter is used to level of the top of each ink layer printed, rendering it flat for the next deposit of ink. (Objet, 2004) [15] Although the use of additional processes allows greater control over cross-sectional profiles, they also pose severe drawbacks:

1. It complicates the design of the system
2. It requires two printheads. One for the ink and the other for the supporting gel.
3. It increases printing time, cost and maintenance of the system.

We sought to address the problems of creating different cross-sectional profiles by using a single additive process maintaining the simplicity in the design.

3.3 Methodology

Sequential Drop Placement (SDP) uses an algorithm embedded in the software layer, which controls both the position of individual drops on the substrate and the sequence in which they are ejected and cured. The algorithm analyses the outline of the structure being printed and according to the required cross-sectional profile, strategically places drops within the boundary of the printed object. By doing so, newly ejected drops are confined to the required position by being 'locked' between previously ejected cured drops. Using this method the location and order of ejected drops can be altered to achieve numerous profiles. Thus far we have established three SDP models, resulting in a controlled build up of lines, circles and symbols of a waved shape. The image stored as a monochrome file taking the lowest possible storage space. Similarly, the processing power required in order to analyse the image is insignificant compared with mechanical printing time. Since the algorithm produces up to 4 images from the original one, it increases the overall printing time. The methodology though, has no implications on the machine design, its cost or maintenance procedures.

3.4 Implementation

To produce a straight edge profile (see figure 7b) for example, the algorithm analyses the image and each object (line/symbol) within it, to determine their cross-sectional orientation in respect to the printhead. Each shape identified is then divided into one pixel-wide line ('single lines' hereafter). Depending on the shape, the division can occur in horizontal, vertical or both directions. Once the file has been processed the 'single lines' are pasted into separate files. (See figures 3, 4 and 5 respectively)

Figure 3: Full Image

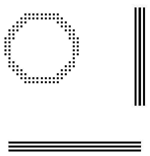

Figure4: 1st part

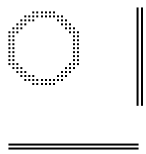

Figure 5: 2nd part

The printing process starts by printing the first image containing the one set of 'single lines', creating the form of a 'zebra crossing'. This is immediately followed by exposure to the ultraviolet lamp, which partially solidifies the printed drops, forcing the next layer of ink (2nd image) to flow into the interstices between, created by the drops printed previously. The process is repeated until the required elevation is reached.

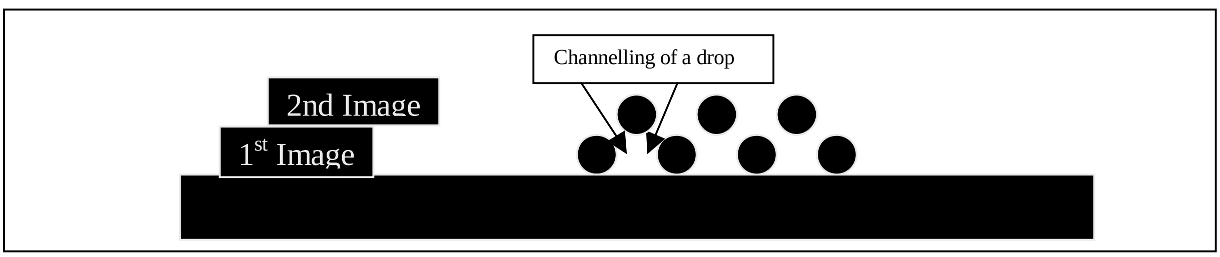

Figure 6: Front view simulation of drop channelling

The process of implementing a different profile for a rounded or wavy shaped symbol may vary slightly, producing up to four separate images; however in essence of the process remains the same.

The following microscopic images capture the cross-sectional profile of lines 13 pixels wide, printed using Xaar XJ500. Across the x axis drops are printed at 180 dpi. The number of drops per inch along the longitudinal axis of the lines (y axis) varies from 360 to 720 DPI. (These profiles are achieved using a single additive process.)

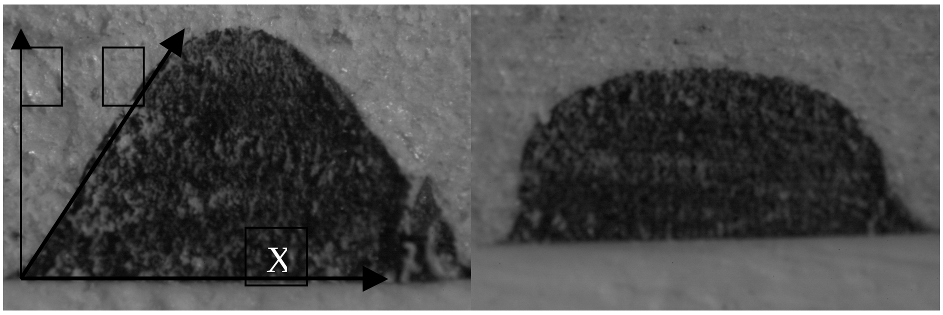

Figure 7a and b: left to right, Normal line and line printed using SDP. 360 dpi

Although the full effects of printing using SDP have not been fully investigated, we have observed a reduction in volume between normally printed lines and those printed using SDP. More importantly following a recent adhesion test, we also found indications that adhesion improves when the SDP printing method is used. This has potential implications on the robustness of tactile maps and their reusability.

4. PERFORMANCE OF VISUALLY IMPAIRED USERS

An initial experiment to test the effectiveness of tactile line profiles and textures against normally printed shapes was devised. . A matrix of circles (6 * 6) was printed using 3 different profiles at 6 different elevations. The three profiles used were *domed* (referred to as smooth), *triangular* (referred to as sharp) and *rough* (a series of Braille dots forming the symbol's shape). The matrix contained full circles and incomplete circles. Seven incomplete circles were randomly located in the matrix and acted as target symbols. Participants were asked to scan the matrix from top left to bottom right, searching for incomplete circles. Scanning time was measured. Seven sighted and 11 visually impaired participants took part in the experiment.

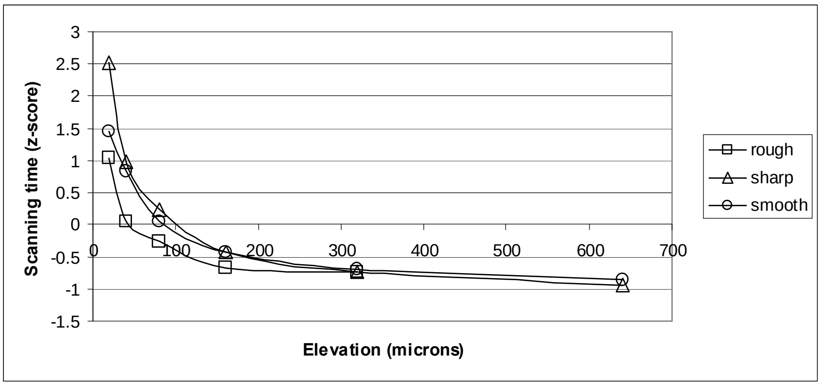

Figure 8: Scanning time on arrays featuring several line types and elevations. – Source: "A scientific approach to tactile map design: Minimum elevation of tactile map symbols" S. Jehoel

Figure 8 shows the results were inconclusive. Even triangular profiles did not show the kind of tactile effectiveness we might have anticipated at low elevations, although they were easier to scan at increased heights. However they covered only a limited number of all possible profiles and involved just eighteen participants. In order to make further judgements on the effectiveness of profiles further experiments, testing more profiles, in different scenarios are required.

5. POSSIBLE USES OF PROFIL IN TACTIL MAP CONTEXT

While it is possible to create as many distinctive profiles as there are colours, because as a means of accessing graphic information the sense of touch is impoverished compared to vision, and we anticipate users will only be able to discriminate between very few profiles, this paper concentrates on ways of exploiting cross-sectional differences to provide supplementary map information. Hence we offer some potential scenarios for using profile in a tactile map context. Symmetrical profiles could be used to provide extra levels of meaning. Here a point symbol such as an outline circle for example might represent a religious building. Different line profiles; square, domed, triangular etc. could help us define what kind of place of worship it is, church, mosque, temple, synagogue etc.

Different symmetrical line profiles could also be used to emphasize elements of a tactile map. Users often speak of the value of skeleton structures and how these aid overall mental image construction. Here they refer to how a basic tactile map framework, usually represented by a network of roads, helps to both lead them around and through the map and to contextualize the geographical relationships of all other mapped information, particularly individual landmarks. This is normally only possible on specific types of tactile map. On larger scale maps such as town plans this means including the ring road and main arterial routes. On smaller scale maps the motorway system seems to be the most common feature about which spatial relationships are established. Using differences in line profile, particularly sharper lines might be one way of improving the efficiency with which visually impaired people pick out these useful skeleton structures.

Both previous examples replicate the use of colour on visual maps to some degree. However it is possible to consider that the tactual qualities of profile could also fulfil unique tactile design purposes. Assuming people can feel different slopes and make consistent sense of them by agreeing a convention about the meanings of steep and gentle sides, asymmetrical profiles could be used to add redundancy to outlines, and in doing so address some of the inherent problems posed by the figure ground conundrum. On smaller scale maps this could account for differences between land and sea, on larger scale maps it could define between the inside and out of buildings. It is important to remember how accessing spatial information using touch varies as a consequence of differences in visual as opposed to tactual perception. The vastly reduced resolution of the fingertip compared to the eye means that most tactile design guidelines recommend that each symbol vary by at least two tactual variable factors to enhance tactile discrimination.

6. CONCLUSION

This paper has demonstrated an ability to exert control over tactile line-profiles using new inkjet technology. It is achieved by combining a single additive depositional process using acrylic ink, with an innovative printing method called Sequenced Drop Placement. Given the opportunity to create tactile structures with different cross sectional profiles, we undertook an evaluation of tactual graphic variables defined by Vasconcellos and proposed a revision by introducing profile as a new tactile variable. Examples of the ways tactile profiles could be deployed to provide visually impaired people with supplementary map information were provided.

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