The Use of Ink-jet to Produce Tactile Maps

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Abstract

Tactile maps and diagrams are raised line pictures used to present graphical information to people with visual impairments, corollary to Braille being used to present textual information. It has been demonstrated that inkjet technology offers a novel and potentially highly efficient means of producing tactile maps.

The technology utilized a custom-built flatbed printer with a 180 dpi 500 nozzle print head and ultra violet curing inks. By only partially curing print layers, sufficient that ink drops on the substrate remained domed, subsequent layers were printed which would cross-link and form a homogenous material protruding from the surface of the substrate. The 180 dpi print resolution inherent of a commercial print head is more than sufficient to exceed the areal tactual acuity of the most sensitive user. The ability to build three-dimensional features onto substrates at resolutions of 180dpi or less means more distinct symbol, line and texture features can be manufactured than by any standard tactile map making method.

Psychophysical studies have revealed that users are able to understand far lower print heights than the previously recommended half a millimeter and there is a preference for matt substrates. Further research will continue to combine materials science and systems engineering principles with those of psychology and cartographic design to fully exploit the technology in such a way that it is of most benefit to the end user.

Introduction

Tactile, or raised line, diagrams are three-dimensional images designed for use by people with visual impairment. They can be used in education, for orientation and way finding, and have many other applications. Tactile diagrams are to images what Braille is to text and are used to reproduce maps, graphs, and technical drawings. They have been studied for over 200 years, but have probably been in use a lot longer.[1] Despite a steady stream of research relating to the use and properties of tactile diagrams through the twentieth century, this has slowed more recently as researchers concentrate on computer technologies such as audio aids and virtual reality. However as more information has become image based, the use of graphics in education, marketing and the media has multiplied and, with increasing dependence on graphical formats on the Internet, this has rendered large amounts of information inaccessible to blind and partially sighted people. As a result, interest in tactile graphics has been rekindled.

Existing methods of tactile production each have advantages and disadvantages, but none really makes full use of the potential versatility of representing graphics using digital data. Applying inkjet technologies to tactile map production is not new, indeed several groups have attempted it before.[2-4] However our development has taken the process a stage further by producing quality robust tactile output. It is based on a machine developed by Patterning Technologies Limited for the printed circuit board industry, based on the ideas of Dr. Stuart Speakman. Our team recognized the potential such an accurate ink jet process might have for printing tactile diagrams. A prototype machine commissioned in early 2000 has formed the basis of our research. It has also been used for limited production runs of printed tactile output.

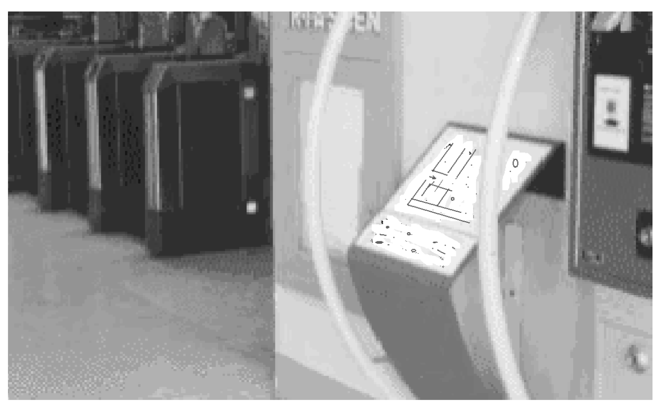

Figure 1. Tactile map in service at a train station.

A research group comprising of both materials and systems engineers working in conjunction with a cartographer and psychologist has been formed. Such interdisciplinarity should ensure that the technological innovation is sensitive to the human aspects of the work in meeting the needs of potential users; blind and partially sighted people. Accordingly the project has been named the Tactile Inkjet and Mapping Project – TIMP. Data on mechanical, material and performance indicators is being collected in order to optimize the process. It is hoped that this will also lead to a miniaturization of the process to make it cheaper and more widely available. This is but one of many trends in ink-jet technology occurring concurrently. Indeed ink-jet is also being used more widely for the production of three dimensional structures by rapid prototyping, for use in biochemistry and electronics.[5, 6]

Background

Details of the methods used to manufacture these raised line diagrams are well documented.[7,8] Of many methods used for producing legible tactile diagrams, the most common are swell (or microcapsule) paper and thermoform.[9] Mixed media diagrams are also popular. Mixed-media is the term used to describe an approach that involves bonding materials such as cloth, string, cardboard, matchsticks and sandpaper to a base to create an image in the form of a collage. Though obviously a very simple method it is considered to be effective In some ways mixed-media tactile diagrams are the 'best' as they offer the full range of textures and materials. The perceptual differences between sandpaper, solder wire, string and even grass clippings are immediately recognisable as the scent, sound, slip and spring of the materials all contribute to perception. This advantage is off-set by being among the slowest, least reproducible, and dimensionally inaccurate of all the methods.[10]

Swell (or microcapsule) paper is probably the most popular method of tactile map production.[10] A thick backing paper (>180gsm) impregnated with temperature sensitive microcapsules containing alcohol is fed through a desktop printer, and an image printed onto the paper in the normal way. The paper is then passed under a controlled heat source, whereby the areas printed with black ink swell and raise from the surface of the paper as the microcapsules expand due the increased temperature. Swell paper diagrams suffer from poor dimensional accuracy, as there is a level of directional unpredictability in the expansion of the microcapsules. The paper is soft and fragile and raised features may also be somewhat 'fluffy' and therefore prone to misinterpretation.

Thermoform diagrams are produced by vacuum forming a PVC sheet over a master male pattern. The PVC sheet sold specifically for thermoforming are typically matt, non-toxic and moisture-proof and slightly textured for users comfort.[8] The master pattern can be re-used, the diagrams can be relatively high (>10mm,) with varying feature heights and the polymer is relatively tough, but there are considerable drawbacks. There is loss of information with the thermoform cast when compared to the master, as the elasto-mechanical properties of the polymer become the limiting factor.

Other technologies used for tactile diagram production include manipulating Braille embossers modified so that the hammers print out images and the use of electro-rheological fluids.[11, 12] For studies that have required detailed analysis it has been necessary to mill or etch[13, 14] or use other precision engineering processes, which are generally too expensive at the small batch sizes typically required by researchers. This has led the research to explore the piezoelectric inkjet process for creating tactile diagrams.

The TIMP Prototype Machine

A prototype machine was commissioned in order to further the study. The machine contained one 500 nozzle binary piezoelectric printhead, a 3 axis flat bed set-up able to hold substrates of varying thickness up to 380 x 480mm and a 300W/cm microwave UV lamp for curing. The drop sizes (~50µ), deposition rates (10g/min) and print resolution (>180dpi) of industrial ink-jet print heads have been broadly successful. Generation of an A3 tactile map, with 400µ high features takes around 15 minutes, though improvements to the process mean this is constantly being reduced to approach a theoretical limit of around 70 seconds.

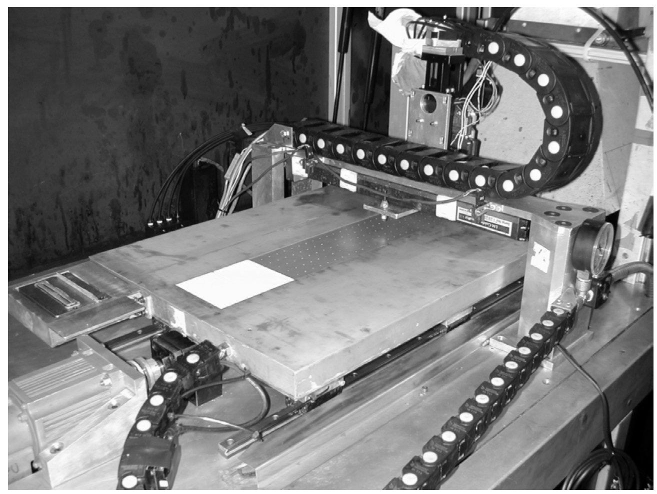

Figure 2. The substrate table and main process area of the TIMP machine.

A range of polymers (PVC, Polyester, ABS) and papers have been proven to be effective backing substrates. Coloured and clear inks, both rigid and flexible when cured, have been much liked by user groups.

There are other developments with ink-jet that have demonstrated it's use as a method of creating three-dimensional structures. Ink-jet is used in a number of ways in rapid-prototyping; delivering binder to powders, and direct deposition of both wax and polymer ink systems. Other three dimensional process have seen ink jet build up structures for electronics, micro machines, bio-chemistry, optics and medical purposes.[15]

This paper now describes some experiments and developmental work that has been undertaken to refine the production process and finished tactile maps produced on the TIMP machine.

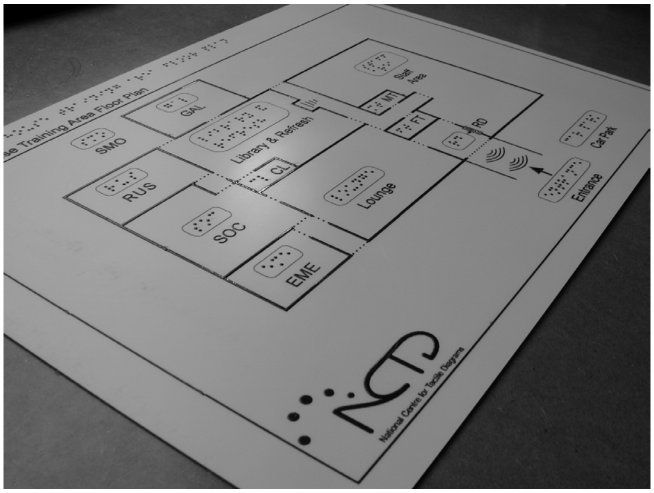

Figure 3. Tactile map produced from the TIMP machine.

Experiments

Influence of Background Substrate

A lot of feedback from early fieldwork related to users' preferences for background substrate. A fundamental requirement of a machine or production methodology would be the way in which in it handles the substrate to be printed on. The working of a machine printing on flexible paper or film sheet would be considerably different from one printing on a rigid polymer board. An experiment was set up to test users preference and performance using different substrate. Originally search tasks using pseudo-maps were proposed but the problems of equivalence between different maps could not be overcome, so a more abstract search task was devised. A series of arrays was printed; a standard UV curing polymer ink was printed to a height of 400 micron on 7 different substrates. including papers and polymers with matt and gloss finishes and aluminium. The time taken to find a random distributed target symbol was recorded. Users were also asked to rate their preferences for the substrates.

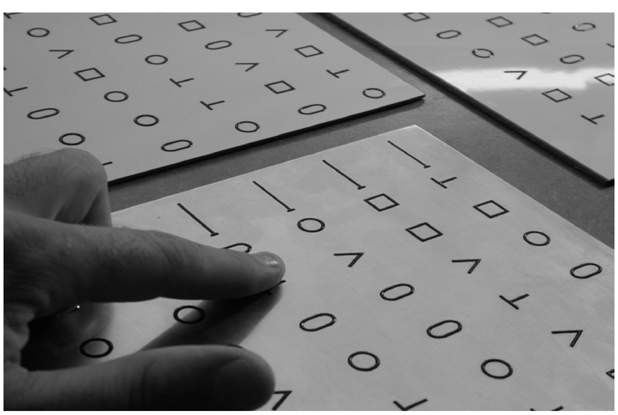

Figure 4. A participant testing one of a series of seven different substrates.

There was a tendency for participants to prefer matt finishes over shiny, with no clear preference for paper over polymer. Aluminum was the least favoured, mainly due to it's feeling of coldness (which is true for all metals and comes about as heat is removed from the finger more quickly by the higher conductivity). Preliminary analyses indicate that matt products were searched faster. This may be due to environmental conditioning of the finger on a 'warmer' surface, more contrast with the shiny ink, and/or a tendency for fingers to irregularly slip and stick on the shinier surfaces.

Mean ranking of background substrate.

Substrate	Mean Ranking
Microcapsule Paper, Zy-tex	5.7
Matt paper, Fasson SU 5134	5.2
Matt PVC, Brailon	4.0
Shiny Paper, Fasson SU5142	3.9
Shiny Plastic, HIPS	3.8
Matt Plastic, HIPS	3.5
Aluminium, 1mm Drill Press	3.0

Elevation and Identification of Printed Features

The elevation of printed features off the substrate is an important factor. In the TIMP process higher features are produced by printing more ink, meaning more material and longer print time, thus higher cost. Recommendations for Braille and tactile elevation typically state heights about 400-500 micron. Psychophysical studies have found an ability to *detect* etched features as low as two and three micron.[14,16] A experiment was set up to test the *identification* of printed geometric shapes at varying heights and areal sizes. One print pass at 360 x 180 dpi of a standard industrial UV curing polymer ink coalesced to a height of 10μ when printed on a matt PVC substrate. 2 print passes was approximately 20μ and so on up to 10 passes being approximately 100μ.

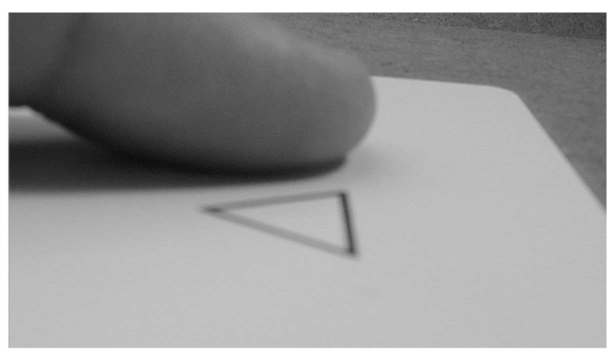

Figure 5. A participant trying to identify a symbol.

Experienced Braille users were readily able to identify shapes correctly at 10µ. This is only one print pass at the standard print resolution of 360x180 dpi (drop ∅50µ). The areal size has more effect on identifiability, with a sharply deceasing percentage of users correctly identifying shape once dimensions decreased below 5x5mm, but nearly all users identifying shapes larger than this regardless of the elevation from the substrate. This is a positive finding for machine manufacture and development as it seems likely that the 400-500µ elevations will not always be required, though one must be wary of inferring from laboratory findings to real world map using tasks.

Further research on the elevation and in particular the nature of the ink coalescence and build up is being undertaken. Of particular interest is the generation of vertical or near vertical walls up from the substrate.

The Influence of Contact Angle and Time to Cure

Small drops of fluid at rest on a surface will have a contact angle with that surface governed by the interactions of the surface tension of the fluid and substrate. The contact angle is useful in describing the geometry of the drop. Contact angle is commonly related to surface tension by Young's equation or complex derivatives of Young's equation; the science of wetting and surface tension becomes awkward at small sizes, where the gravity force effects (typically forcing a drop to spread) are comparable to the surface tension and internal bonding forces effects (holding the drop together.)

The science dealing with drop diameters (50±10µ) as typically used in this work is not as problematic as when drop diameters are less than 1µ, though more complex equations that take into consideration roughness, contact angle hysteresis and apparent and actual contact angles need to be investigated.[17] It is also difficult to measure accurately the surface energies of solids.[18] The ink-substrate systems commonly used, ultraviolet curing inks on polymer substrates with minimal absorbance, have been adequately described by the Owens-Wendt geometric mean.

$$(1+\cos\theta)\sigma_l \approx +2\sqrt{\sigma_l^d \sigma_s^d} + 2\sqrt{\sigma_l^p \sigma_s^p} \qquad (1)$$

where σ is the surface tension of the liquid (l) and solid (s), polar (p) and disperse (d) components.

Measuring equipment that generates a pendant drop and uses software to interpret video images can be used to monitor the contact angle over time. The video in this test equipment is set at 15 frames per second so it is possible monitor and record the decrease in contact angle till the drop reaches equilibrium.

In a pilot study, three standard printing inks with similar properties were tested against seven typical substrates used in the printing of tactile maps. The results are plotted in Figure 6. There is difference in behaviour not necessarily related to ink type of substrate type, but the interaction between the two materials. In particular the differences in the first second could have significant effect on the final product.

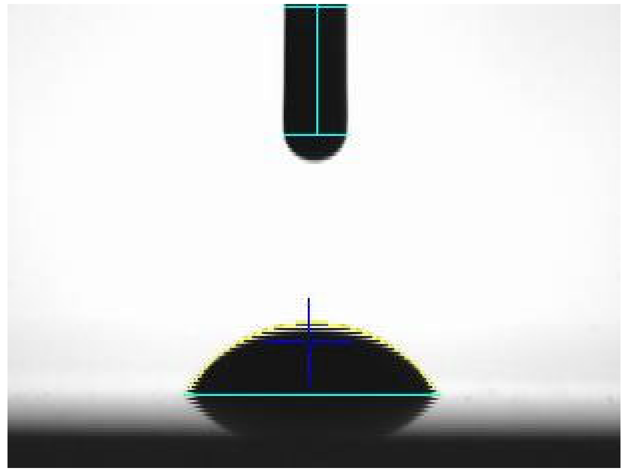

Figure 6. A still taken from footage of a drop formed by pendant drop method .

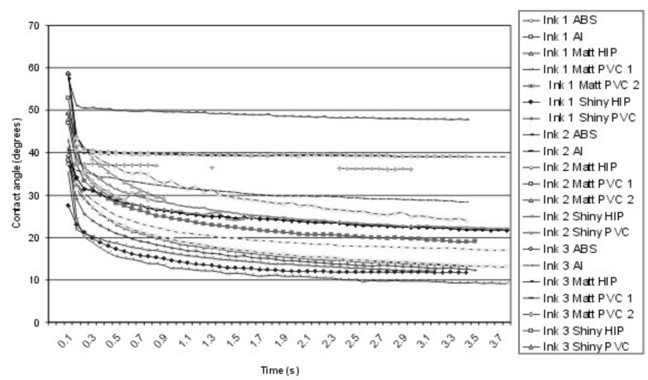

Figure 7. Contact angle of three inks on seven substrates

UV Curing

It is theorized that by only exposing the UV curing inks to reduced doses of UV light, the inks will not completely cure, with some of the ink remaining liquid. Another layer of ink placed on top will thus have a chance to diffuse with the previous layer. Cross-linking of polymer chains will occur between the layers and a homogenous solid polymer formed. Microscopy of ink has shown this to be the case.

The partial curing can occur to such an extent that it will hold the shape of the drop – stopping it from spreading any further. This is advantageous as this process is concerned with generating height.

Modelling

Given the contact angle of a drop of ink, it is possible to approximate its shape at a given time and partially cure it to that shape with the required amount of UV light. A model can be set up to predict how the drop array might look.

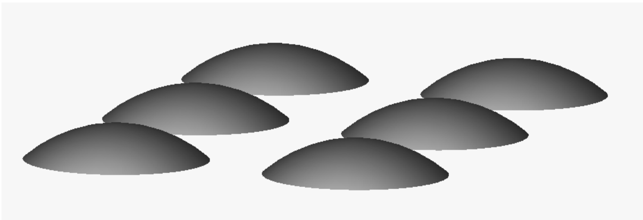

Figure 8. CAD generation of a single layer of 50µ drops printed at 180dpi. In this model the drops have spread to a diameter of 105µ and height of 20µ.

The behaviour of subsequent layers of ink is more problematic, and the contact angle and coalescence of the ink on itself, and on varying degrees of partially cured ink becomes less predictable. The TIMP project will use computational fluid dynamics (CFD) methods as an aid to modeling and predicting how structures might build up.

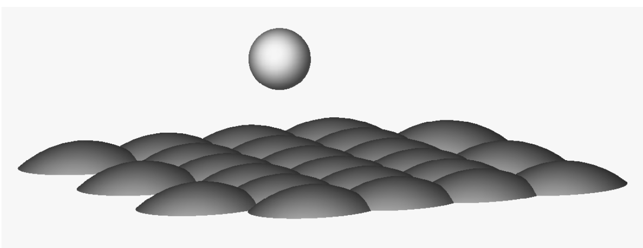

Figure 9. A first layer of 50µ drops printed 360dpi. The prediction of the behavior of the next layer of ink is more problematic.

Figure 10 demonstrates the degree of accuracy, placement and verticality that is achievable using ink-jet. The drops have landed on top of each, other and a combination of speed to lamp and high contact angle have kept the drops columns vertical. The angle comes about as the time to impact lessens with increasing height and is easily overcome by raising the print head.

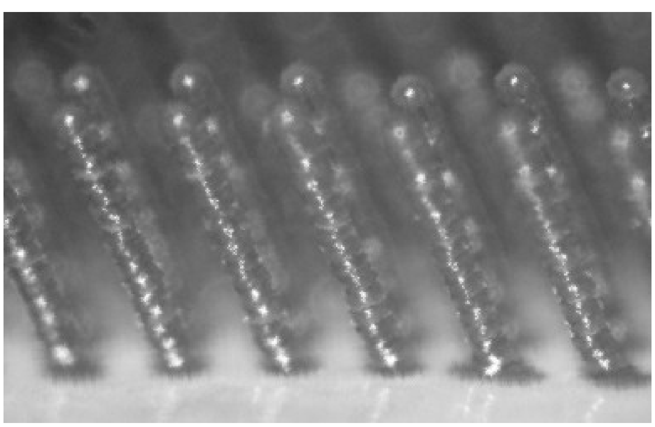

Figure 10. 180 dpi ϕ50µ drops of ink printed with such precision as to produce these 'stalagmites.'(Image courtesy of INCA Digital, Cambridge, England.)

Figure 11 shows micrograph of standard polymer ink on a aluminium substrate. The drops have maintained their individuality in some areas but coalesced and spread in others.

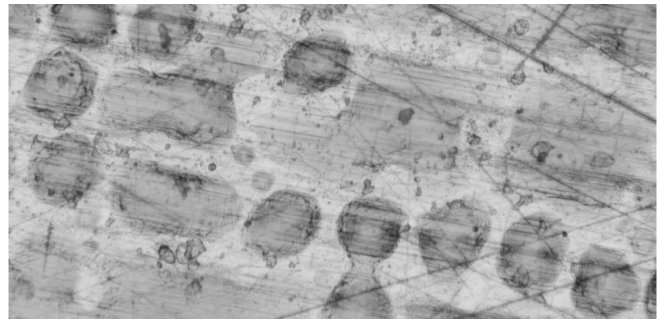

Figure 11. 180 dpi drops showing a localized variation in coalescence.

Conclusion

The construction and development of a prototype machine has clearly demonstrated the feasibility of using ink-jet as a method of tactile map production.

The interdisciplinary nature of the research has been successful with psychological, psychophysical, cartographic and neurological input to the engineering design. The identification of preferred substrates and the empirical support for lower feature heights has had influence on the engineering design.

Simple models of the three dimensional structure have been developed showing how idealized three dimensional structures to be used on tactile diagrams can further meet the findings of behavioural scientists and more importantly the people using them.

Acknowledgments

The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC) for their funding of the project. (Grant number GR/R94480/01, the Principal Investigator is Emeritus Professor Derek Sheldon of Anglia Polytechnic University). We would also like to thank the Enterprise and Innovation Office of the APU for their continued support to this program and Patterning Technologies Limited (PTL) for their valuable technical advice and use of facilities.

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Biography

Don McCallum graduated for the Australian National University in 1996 with an honours degree in Electromechanical Systems Engineering. After 3 years working in the West Australian mining industry he moved to England in 1999 to take a position researching and developing tactile maps and the machinery to make them. This has become the topic of Don's PhD research, which he is part the way through. He was born and educated in Canberra, Australia and now lives in Cambridge, England.