Continuous Tone Colour Printing in Two and a Half Dimensions Through a Combination of 19th Century Analogue Methodologies and 3D Printing

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Abstract

This paper proposes a contemporary method of continuous tone colour printing based upon the Nineteenth Century printing process of Woodburytype as developed by Walter Bentley Woodbury in 1865. Woodburytype was the only truly continuous tone printing process yet invented, and died out in the late nineteenth century as more expedient and cost effective methods of printing prevailed, thus laying the path for current CMYK print technologies. Digital print itself, since its development as a range of colour printing technologies, has followed a route based on the half-tone dot and four colour separation predicated around CMYK. In recent years stochastic algorithms and dithering have allowed the lay down of multiple passes and colour sets to create a near continuous tone image. The downside of this approach is that in order to create a full colour subtractive image, the resultant prints have very little surface topography and a mechanical uniformity that demonstrates none of the surface characteristics, tactile qualities and rich tonal warmth of the 19th century photo-mechanical processes.

Current research at the Centre for Fine Print Research (CFPR) at the University of the West of England, Bristol, is exploring the potential of CNC milled imagery, where the tonal range of each colour is assigned a physical height to produce a continuous tone topographic relief printing matrix, from which the colour image is cast in a silicone ink. A translucent image is cast from each of the colour matrices and each colour is assembled one on top of another resulting in a true four colour separation continuous tone print, where colour tone is created by physical depth of colour.

Introduction

Since the invention of Walter Bentley Woodbury's 'Woodburytype process in 1865[1], it has been possible to autographically print a true continuous tone black and white photographic image. From the turn of the 20th Century the path of printing technology followed a different and more expedient route of the half-tone dot and the four-colour separation process. This restriction to four colours was necessary because more than four colours printed together using a half tone created an interference pattern or moiré, thus rendering the image unreadable. With the advent of digital technology, the inkjet printer logically followed the four-colour separation route, as four colours required less computational power than a wider colour set of six to twelve colours. For most imaging purposes there is a clear rationale for using CMYK as the subtractive opposite of RGB, however four colours laid down in a dot structure creates a very restrictive palette. It is only in the last ten to fifteen years that computational maths have created the stochastic algorithms and dithering that simulate a random down structure, which has allowed the lay down of multiple passes and expanded colour sets to create a near continuous tone image.

The downside of current digitally printed imagery is its flat surface quality and mechanical uniformity. Particularly when compared to earlier autographic processes, such as letterpress and screen printing which are undergoing a revival, partly for their hand crafted content but primarily because they create a physical and tactile surface that has a subjective quality, hard to define using standard testing methodologies. The CFPR has been reappraising 19th Century print processes for the last fifteen years and Hoskins has published on the continuous tone properties of Woodburytype and its relation to photo-ceramics in previous papers to the IS&T PICT[2] and EI in 2003[3]. This paper builds upon previous research to combine 19th Century Photomechanical techniques with current digital technology[4] and proposes new research to utilise developments in 3D printing to create new methods of continuous tone printing in four colours using new materials. These materials will enable a physical and tactile surface quality that more closely resembles the autographic surface of the Woodburytype and the three colour Carbon printing processes.

This research is now possible, as a number of factors have come together to enable a reappraisal of continuous tone printing. 3D printing has come of age and there is software readily available that will split a photographic image into a bump map image where the Z-axis corresponds to a set of height steps on a tonal step wedge from black to white. This software is easily transcribed to either a DXF for processing in G Code to CNC (Computer Numeric control) mill an image or into an STL file for 3D printing as a low relief tonal surface.

Historic Context

In order to put into outline the steps leading to this research, some historic context is necessary. All of the following processes are based upon the light sensitive properties of bichromated gelatine. In 1865, Walter Woodbury patented his continuous tone photographic relief process that transcribed a black and white photograph into a tonal relief surface. Woodbury created a slab of gelatine approximately one inch thick (25mm) to which was added a 3.5 per cent solution of Potassium Bichromate, making the gelatine light sensitive. When exposed to a photographic negative the gelatine hardens in direct proportion to the light it has received. Once washed with water the gelatine forms a tonal relief 'bump map topography' in three dimensions, with the dark areas standing proud and the white areas forming the valleys. Woodbury then made a lead matrix from the gelatine block. This enabled him to create continuous tone prints in hot liquid translucent gelatine ink from the lead matrix. This matrix was the opposite of the gelatine with the dark areas forming the valleys and the light areas standing proud. When cool, the tonal range of the prints was entirely dependent on the depth of gelatine, i.e. the thicker the gelatine the darker that section of the print. The prints were made by pouring hot liquid gelatine, coloured with black pigment into the matrix, then placing a sheet of paper on top and placing both matrix and paper into a press and exerting pressure. The print was formed from the relief matrix and when cool, shrank to create a subtle and accurate black and white photographic image. The problem with the process was that the hot gelatine squirted out from the sides of the matrix, therefore the prints had to be trimmed to the size of the image, and then pasted into the book or publication they were intended for.

In his practical study of early photomechanical processes, 'The Keepers of Light', Crawford[5] argues that the three-colour carbon process invented by Louis Ducos du Huron in 1868 was the earliest commercial three colour photographic process. Three colour carbon was based upon three separate layers of light sensitive coloured pigmented gelatine (Cyan, Magenta, Yellow), each layer was individually exposed and mounted on three separate sheets of transfer paper then each separate coloured image was transferred from the intermediate transfer sheet and placed and registered one layer at a time on top of each other on a backing sheet of white paper.

Both of these processes are fundamentally continuous tone, three colour carbon is generally accepted within the field as a photographic process as the prints are individually exposed and for many years was a staple colour process for photography whereas the Woodburytype is a printing process from a lead matrix.

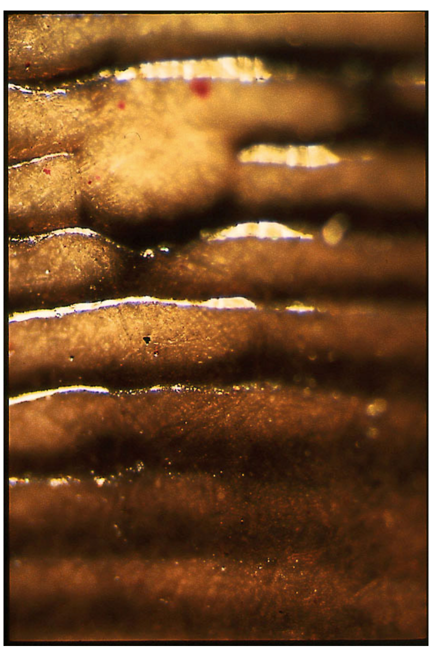

***Figure 1**. Microphotograph of traditional Woodburytype 30x magnification. (This image is of a Woodburytype reproduction of a line engraving hence the linear structure)*

Between 2001 - 2003 The CFPR used CNC technologies to create low relief continuous tone photographic images in ceramics.[6] These images were created by converting a photographic black and white file into 256 tones of grey and then assigning the grey tones a virtual height in relation to their density in an XYZ axis. This enabled the creation of a DXF file that translated to a machine code in order to CNC mill a ceramic tile. The CNC milling machine then cut the three dimensional photographic image into the tile. Once fired the tiles were then glazed with a translucent black glaze which created the photographic image as the glaze pooled to different tonal depths in direct relation to the milled image. This arguably was a further development of the Woodburytype process, based upon the photo-ceramic tiles developed by George Cartlidge[7] who created his series of portrait tiles between 1901 and 1919, and Walter Ford[8] from Ohio in the 1930's, who filed a patent for a photo-ceramic relief photographic process, casting tiles from bichromated gelatine matrices and then glazing them with a translucent glaze.

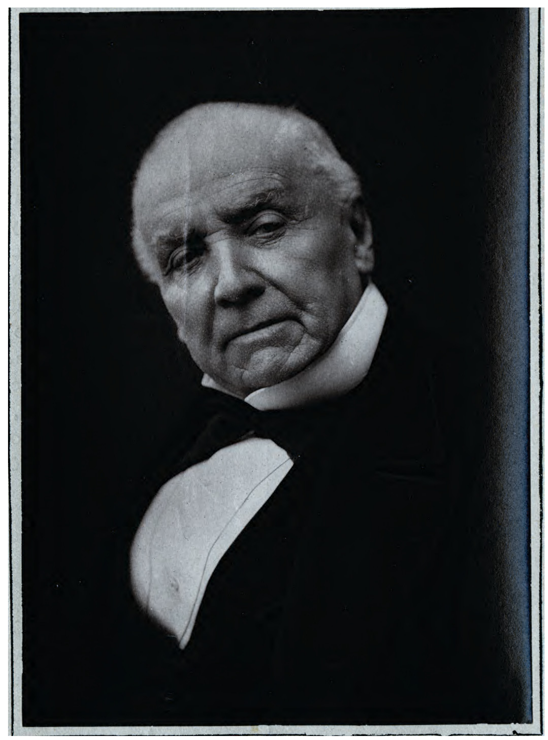

***Figure 2**. Woodburytype from 'Men of Mark' Photography by Lock and Whitfield, published by Sampson Low, London 1876.*
Image size 12cms x 8.6 cms

Continuous tone research

Fundamentally the use of CNC milling to create a printing matrix is of theoretical interest in the creation of a true continuous tone printing process, because the nature of the drill bit cutting tool path which removes any stepping that would normally occur when transcribing a bitmap grey tone file into three dimensions. By assigning a height to each of the 256 tones of grey, each pixel is represented as a cube rather than a square. Therefore if one creates a 45 degree pyramid then the pyramid would be stepped. The tool path smooth's out the stepping, creating a curved surface topography. Here it is important to understand that the transcription does not create pixels or dots but maps points on a tone curve. Interestingly this means that a high definition image can be created from a relatively low-resolution greyscale file. In actuality within the three-dimensional file each pixel is represented as a single point on the tone curve rather than individually using 8 bit data to define a dot. This means that much less computational power is needed to create a very accurate continuous tone image rather than needing 8 bits to define every single dot.

The current project is to build upon this previous research, which demonstrated the potential of high quality tonal imagery in black and white - generated through a surface relief. The aim is to create a more demonstrably practical process and theoretical methodology for surface relief printing (2.5D printing), initially in four colour continuous tone and ultimately in multiple colour sets. In 19th Century processes such as collotype, the image was created by building the coloured image up in a series of layers one on top of the other, this created a physical surface where the light travelled through the layers in a path that was determined by the combination of coloured layers and the density of the pigment used, thus creating a more varied and interesting visual appearance that was not necessarily predictable. The objective of this project is to create a set of four-colour moulds using both CNC and 3D print technology to create low relief printing matrices, from which the images will be printed. To achieve this we are aiming for the relief to be based upon the tonal height of the original Woodburytype prints, which when the gelatine had dried completely came down to a measurable cross sectional height in the region of 0.13 mm (.005 inch) (See image 7). In order to create a print the matrices are filled with a liquid pigmented silicone and to ensure quality of image the matrices are placed in to a vacuum chamber to remove all air bubbles and to fill the mould accurately. The individual layers are then transferred to a paper substrate in the same manner as the original carbon process.

***Figure 3**. Photoceramic continuous tone tile, CNC milled by CFPR fired and glazed with a translucent black glaze*

The CNC process for creating matrices

Matrices have been manufactured both by CNC milling on a Roland MDX 540 mill using a 0.25mm bit and 3D printing using an Eden Objet 500 printer, with a range of cross sectional heights from 0.13mm to 1mm.

For purposes of clarity, although it has proved possible to print matrices on the Objet 3D printer, however the results show a more marked visual stepping. This is due to the way that the Objet lays down the photo-polymeric light sensitive resin one layer at a time by ink jet, curing each layer with UV light as it is printed. This layering process creates stepping between each layer, which is not a feature of the continuous tone process and is easily identified in the cast prints. Therefore the results of the 3D printed matrices are not included within this paper.

One problem was identifying suitable substrates to mill that would also release the silicone and would not add an artificial surface texture to the image, or stick to the block and only partially release. To date we have tried various densities of polyurethane model board in order to ascertain the optimum balance between quality of image, cutting time and possible breakage of drill bits. A small image of 3 inches square can take up to 7 hours to mill if using a 0.25 drill bit with a 0.1 step over. The examples shown in figures 4,5,6,7 have all been milled into polyurethane model board, more recently experiments have been undertaken with cast polyurethane and cast resins as these should give a higher quality of milled finish and therefore an improved visual image quality. One route being investigated is a modification of Woodbury's Stannotype process. In this extension of his earlier work Woodbury substituted a layer of tinfoil onto the exposed and developed gelatine rather than take a lead matrix from the gelatine mould. In our case we have used aluminium foil to cover the CNC matrix in order to give a smooth surface to cast from. Whilst this is an improvement on the varnished polyurethane surface it does not have the qualities offered by cast polyurethane.

The matrices have to be capable of being cast and printed under high pressure, at this early stage of the research it did not seem expedient to create a special hydraulic press to print the results as only very small numbers of prints were being created. Therefore once the matrix has been created the surrounding area is drilled at regular intervals in order to be threaded through with a number of bolts, which form the basis of the clamping mechanism. A sheet of acrylic is drilled with a matching set of holes and once the matrix has been filled with silicone the acrylic sheet is placed on top and the whole structure is then screwed down using wingnuts.

Printing from the matrix

The silicone ink is a proprietary coloured silicone used in the model making industry. The two part catalytic silicone is mixed and placed into a vacuum chamber to remove any bubbles and to ensure even distribution of colour, after the silicone is placed on the plate it is returned briefly to the vacuum chamber to ensure it has no trapped air. Once cast the images are left overnight before removal from the matrices. At this stage the paper has either been placed in the mould - before the acrylic sheet is placed on top and clamped down -, or the acrylic sheet is coated with release agent and the paper is adhered to the cast image after it is dry and is used to pull the image from the mould, both methods are successful.

Currently little research has been undertaken into a suitable support substrate, good results have been obtained from a range of paper and plastic support materials. Standard 90gsm bond paper has proved adequate along with a lightweight vinyl substrate; both have been used for the research results demonstrated.

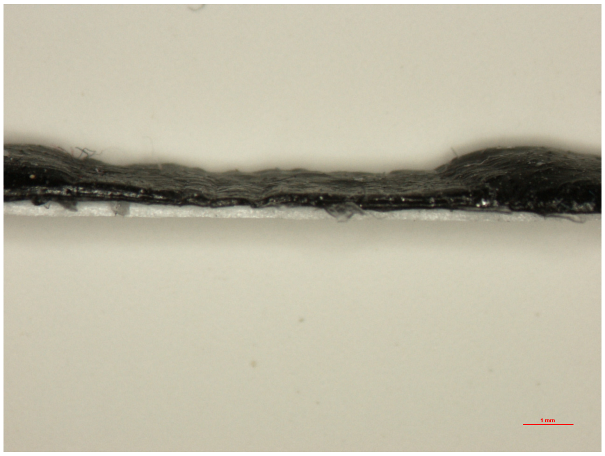

***Figure 4**. Microphotograph of cross-section through a single colour CNC milled continuous tone relief print cast in silicone. Scale 1mm*

The problem of the image sticking to the matrix was identified as an issue early in the research. The initial response was to follow in the steps of Woodbury[9] and use a release agent. First, shellac was used to seal the blocks and then wax was employed as the release agent. Woodbury himself started with olive oil as a release agent, as documented in his personal notebooks part of the Royal Photographic Society Archives, now held by the National Museum of Film and Photography in Bradford, UK. The modified Stannotype process[9] assists in this respect and the answer seems to be in the relationship between a very smooth milled surface from a material such as the cast polyurethane and a compatible release agent.

With regard to how one printed colour is laid on top of the other, currently with two colour prints one matrix is milled with a right reading image, the second matrix is milled as a reflection of the first. The first colour is cast in the matrix and the acrylic sheet laid on top and pressure applied, when the silicone is dry the pressure is taken off and the block taken apart. When the acrylic sheet is removed this leaves a smooth flat surface on the back of the print which is still in the printing matrix. To make the second colour print, the second block is charged with silicone and then married to the first block, which still has the first colour print attached to it. This results in a colour sandwich, with the two coloured layers having a relief surface on the outside of the sandwich and the inside being a smooth surface with the two in perfect contact.

With four colour printing it is intended to try two methods of production, the first is to simply sandwich each cast layer one on top of the other after they are set and place them in a vacuum chamber to make sure there are no air pockets between the layers. This will create a very physical surface topography between the lightest and darkest areas of the print, even if the layers are individually only 0.125 mm the combined total could be as much as 0.5 mm difference in total between the highlights and the darkest areas. The second method is to create a transparent layer on top of each of the cast images, to create a uniform surface thickness and then to sandwich the layers together. This method although expedient is viewed more as a control, as it is believed the transparent layers will affect the way the light travels through the final print.

One problem with undertaking this type of research into continuous tone printing is how to present accurate data that reflects the quality of the image. An example of this problem can be seen by measuring the density of an original Woodburytype print. Conventionally a successful print would be deemed one that had a high Dmax - possibly 1.8 or better and a white in the range of 0.1 or lower. The Woodburytype example used in this paper, from the book 'Men of Mark' by Lock and Whitfield, published in 1876 by Samson Low of London[10], when measured with a RT 120 Techkon densitometer reveals a reflective highlight reading of 0.15 and a black of 1.64, so in contemporary terms this would be taken as a poor reproduction of the image. It is acknowledged however that when viewed in the flesh Woodbury prints have a warmth and tonal range across the mid-tones that is unsurpassed by modern reproduction techniques. Density ranges measured on silicone prints taken from the early results of our experiments, give density ranges between 0.28 and 1.69. D Max readings, which is in line with the historic Woodburytypes.

Future research will lower the physical relief height of the tonal range. 1 mm was chosen initially to be able to visualise the respective heights and to understand whether the process was practical and capable of demonstrating the results of the theoretical approach. It is aimed to create blocks that will more closely reflect the final surface characteristics of the Woodbury original prints with a height profile closer to 0.125 mm, however it is also anticipated that depths less that 0.25 mm may not easily be achieved with the current methods of manufacture. And still enable the prints to easily release from the matrices.

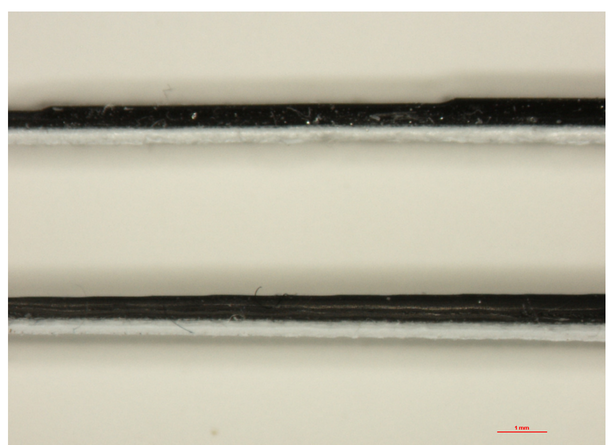

***Figure 5**. Microphotograph of cross-section through a single colour silicone relief step wedge CNC milled continuous tone relief print cast in silicone. Top layer is from a Stouffer step wedge converted to heights. The bottom layer is the same tonal range in continuous tone. Scale 1mm*

Conclusion

In conclusion the process aims to create a digitally generated physical tactile surface capable of being transferred to a range of substrates, which demonstrates the potential for future research into new methods of continuous tone printing.

This research is part of a larger parallel research project to investigate the potential of creating a physically printed relief surface that better represents the autographic mark making requirements of visual artists and designers.

At the time of writing the researchers have achieved the ability to create a successful two-colour print that highlights the potential for the research. The aim of the research is to create a printed full four-colour set to demonstrate the potential of a true continuous tone colour printing process from a digitally generated file that has a physical relief structure that more closely reflects the autographic mark making characteristic of traditional printing processes. Once the objective of printing a four colour printed set has been has been achieved. The goal will them be to create consistent reproducible results from the process. Finally a full set of colour measurements will be taken to determine achievable gamut and map the potential colour space. These results will also be balanced by an appraisal of the subjective qualities of the final four colour prints and all of the findings will be published further.

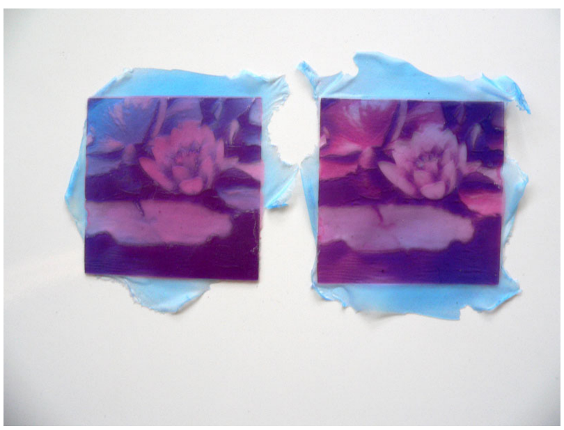

Figure 6*. Early experiments in two colour continuous tone silicone relief prints, prints taken direct from the mould.*

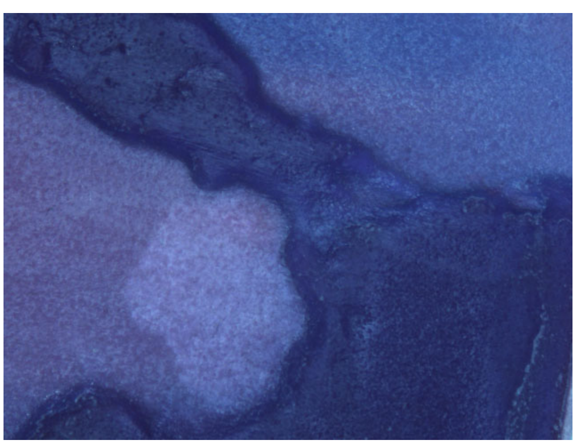

Figure 7*. Microphotograph of a single colour silicone cast print showing the different relief areas and the lack of half-tone structure 30x magnification*

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Photography by Lock and Whitfield, published in 1876 by Samson Low of London

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