Painting by Numbers: Transforming Fields and Edges to Vectors

Carinna Parraman, Paul O'Dowd, Mikaela Harding
The Centre for Fine Print Research, University of the West of England,
Bower Ashton Campus, Kennel Lodge Road, Bristol, BS3 2JT, UK

ABSTRACT

This paper considers alternative approaches to image making and printing that moves from the on-screen representation of images and painting applications, to the physical generation and methods for surface deposition or *2.5D printing*. The research investigates the application of new materials and print processes, as an alternative to four-colour separation and half-toning and departs from traditional halftone screening that uses a vector approach to image construction. The first aspect of the paper describes a non-photorealistic rendering image segmentation algorithm that is used to create a series of colour texture layers. The second part of the paper describes a preparatory UV curing additive that can be used to increase the textured qualities of the brush strokes.

1. INTRODUCTION

The theoretical and practical objective of this research is to gain a deeper understanding of how physical artworks can be created that incorporate both analogue (paint, ink, graphite) and digital (vector); and could be described as containing textural or 2.5D qualities.

Contemporary printing has evolved as a process that is capable of printing flat areas of colour, alongside text, blends of colour and photographic images. In the emerging 2.5D and 3D print market, there is now a requirement to develop methods that can reproduce textures that have the look and feel of, for example, brushstrokes of old master paintings, or as created in a painting software. Current colour painting software tends to mimic how layers of colour are applied as if one were painting. Research so far has considered the shape of brushes, edges, opacity, pressure but less so about the textural qualities of the brush mark or the over-layering of layers of colour, or how to simulate watercolour, ink, oil paints and acrylics.

Texture is a visual attribute that enables us to distinguish the differences between materials (substances or substance out of which a thing is or is made), identify the structure and shape of objects, and discriminate edges in a complex pictorial scene. In order to gain an understanding to create verisimilitude with materials, we can study lighting techniques, drawing and painting techniques used by artists (Bayer, 2004; Hollman, 2004; Jordan, 1995; Constable, 2007) along-side scientists working on human vision and texture perception. Three main characteristics identified as useful in determining the qualities of a surface texture are: value, repetition and edges. (Landy, 1996; Klatzky, 2010) In our search for an identification of what are the basic constituents to identify, classify and reproduce texture, (Marr, 1980) differentiates between image and representation, and the use of what he describes as *primitives* to describe a shape. There are two primary classes of shape primitive: surface based (2D) and volumetric (3D). Of special interest, volumetric primitives involve the spatial distribution of a shape and vectors to describe its dimensions, along with shading and texture gradients.

In previous research, the authors considered how by observing the brush strokes of painters, (Parraman, 2012; 2013) images can be generated through the use of lines, modulation of similar strokes and a repetitive over layering of paint. Inspired by the meticulous painting methods by artists such as Van Gogh and Seurat, the objective for the experiment was to create a vector-driven painting machine that applied a brush loaded with paint to paper in a methodical and mechanical way, yet remain human analogous.

Whilst a vector approach (digital format) is highly machine repeatable, the resulting individual painted brush strokes (analogue) are not. We study the creation of non-uniform but harmonious painting effects across paper substrates through the actuation and placement of the brush, and the flow of paint. We are developing a contemporary approach that is based on vector or .SVG (Scalable Vector Graphics), which provides a set of instructions to drive CNC paths. In software programmes, a vector path is a series of mathematical elements that describe a set of lines, curves, arcs, and a combination of all to form closed shapes. A path can be *stroked* to obtain different thickness or colours, or used as input for other elements such as pressure, gradients in height, and blends to include opacity and translucency. We consider a vector-based drawing philosophy as significant to gaining an understanding of alternative approaches, which break away from pixels (digital screen resolution) and halftones (analogue print resolution).

2. RELATED LITERATURE

Non-photorealistic rendering (NPR) is a body of research which interprets digital formats (captured visual scenes or original works) and renders them with an alternate artistic expression. Typical source formats are pixel based images, although NPR can also be derived from 3D models and determined algorithmically without a prior source.

The utility in NPR can be functional, for instance 'unrealistic' shading schemes aid in the visualisation of complex parts drawn in computer-aided design (Gooch et al, 1998). The utility of NPR can also be to provide a purely artistic interpretation from a source, or to provide interactive software tools to aid in the creation of stylised digital art works. Of particular interest, a subset of NPR is stroke based rendering (SBR) which interprets pixels to strokes. We consider strokes as analogous to vectors, representing a series of movements with magnitudes and directions.

Often SPR seeks to emulate famous painterly styles, such as impressionism (Kasao, 2006; Yang, 2008), oriental ink painting (Ning, 2011; Cheok, 2007), or pen-and-ink illustration (Winkenbach, 1994). In this way SPR is motivated to model characteristics of effectors (i.e. a horsehair brush), mediums (i.e. watercolour) and substrates (i.e. canvas) to synthesise a convincing screen based render (Curtis, 1997). Our motivation is not to render the illusion of painterly styles with pixels. Rather we explore the operation of print apparatus for the tangible production of texture, which originate in painterly styles. As such the characteristics of effector, medium and substrate are inherent to the apparatus we use; we are focused on deriving the appropriate effector movement from digital sources.

We draw on NBR literature for algorithms to determine image segmentation, stroke placement and stroke characteristics that are transferable to machine control, detailed in section [3]. We intend to send a printer a sequence of movements and gestures, rather than a field of pixels to raster to a screen or to scan on to a substrate.

There are many examples of prior works that utilise a machine to produce art in more human analogous ways. Lindemeier (2013) includes a review of early painting machines and related artists; 'eDavid' (Lindemeier, 2013), 'Paul' (Tresset, 2013) and a humanoid robot (Kudoh, 2009) are painting machines that closer approximate human movement. All three approaches utilise digital camera data to compare the working canvas against a digital source image. These three approaches therefore attempt to emulate the progressive development of paintings, stroke by stroke, by utilising predominantly 2D visual feedback during operation. In our approach we attempt to extract this chronological information from digital source images, by interpreting fields of pixels through segmentation and edges, to create a time-series composition of many-layered vectors. We develop this level of automation so that we may later experiment with controlling the generation of texture and expressive mark making.

3. IMAGE SEGMENTATION METHODOLOGY

We have developed a methodology inspired by the NPR algorithms for texture directionality described by Kasao et al through several papers (Kasao, 2006; Kasao 1998a; Kasao1998b). We use the convolution of a source image for texture directionality and edge detection. We implement a simpler K-Means clustering algorithm for image segmentation.

As an iterative algorithm, the K-means clustering progressively divides an image up into a predetermined number of segmentations, with a result analogous to a paint-by-numbers template. We experiment with low numbers of segmentations, such as 16 or 20, as we expect to run each segmentation as a paint layer. The segmentations do not necessarily map the spatial relationship of pixels, nor remain a fixed size of image partition. The segmentations group pixels by their similarity in calculated properties. Each segmentation is re-evaluated to generate the average characteristics of their assigned pixel grouping, thus altering the subsequent criteria for pixel assignment. The iterative algorithm ends when no more pixels are eligible to be reassigned, and therefore the segmentation averages have attained stable characteristics.

The segmentation minimises the Euclidean distance of six variables; x coordinate distance between a pixel and a possible segmentation centroid x coordinate (D_x), y coordinate distance between a pixel and possible segmentation y centroid coordinate (D_y), a pixel edge strength versus a possible segmentation average edge strength (D_e), a pixel texture directionality versus a possible segmentation average texture directionality (D_d); and the distance in colour space between a pixel hue, saturation brightness value, against the average hue, saturation brightness of a possible segmentation (D_h, D_s, and D_b respectively).

The variables D_x, D_y, D_e, D_d, D_h, D_s and D_b are given weighted influence by a fixed gain value, *Kx, Ky, Ke, Kd, Kh, Ks, Kb* respectively. In this way, an image can be segmented with little regard for pixel spatial relationship (K_x, K_y as small values, 0.01 works well), and high regard for texture directionality and edge strength (K_e and K_d as large values, such as 2.5). The Euclidean distance is thus calculated between each pixel and each segmentation (D_{ps}) as:

$$\Delta x = \sqrt{(D_x * K_x)^2}$$

$$\Delta y = \sqrt{(D_y * K_y)^2}$$

$$\Delta d = \sqrt{(D_d * K_d)^2}$$

$$\Delta e = \sqrt{(D_e * K_e)^2}$$

$$\Delta h = \sqrt{(D_h * K_h)^2}$$

$$\Delta s = \sqrt{(D_s * K_s)^2}$$

$$\Delta b = \sqrt{(D_b * K_b)^2}$$

$$D_{ps} = \sqrt{\Delta x + \Delta y + \Delta d + \Delta e + \Delta h + \Delta s + \Delta b}$$

The smallest D_{ps} value assigns the pixel to the related segment cluster. We have used values Kx = , Ky = , Ke = , Kd = , Kh = , Ks = , Kb = to good effect.

The completed segmentation combined with the pixel edge strength and texture directionality provides useful data for machine control. Each segmentation provides the average hue, saturation and brightness values for the assigned pixels, creating a finite palette of colours (equal to the number of segmentations) to paint. The segment average edge strength value provides the order in which to conduct the painting, where strong edges are likely to be outlines or highlights, and performed last in the painting order. The segment average edge strength also provides a means to select a brush size, where low edge strength indicates a uniform area of an image, and so a large brush and a low density of strokes per canvas size can be adopted. Importantly, the information relating to individual pixels is preserved, so the brush stroke length and direction can be mapped from a pixel texture directionality and edge strength, creating a non-uniform characterisation of strokes within a single segmentation of pixels.

4. DEVELOPMENT OF INKS

The second aspect of this project is the development of a water-based UV LED curable medium that can be added to artist's inks and pigments to create a UV curable paint. In normal UV resin bases for inks and paints, the viscosity of the individual components are as low as possible to ensure satisfactory production as well as good flow behaviour of the liquid formulation. However in this application, the resin needs to be viscous in order to hold the texture of the paintbrush mark when the ink/paint is deposited.

UV LED systems potentially offer a greener alternative to conventional mercury vapour lamps used to UV cure coatings for ink, wood/furniture, electronics and other industries. The main advantages of the LED lamps are that they are more energy efficient – using up to 60% less energy than mercury UV lamps, more cost efficient – lamp lifetimes of up to 10,000 hours, and more environmentally friendly – irradiation in the near visible region (380-410 nm), no formation of ozone when curing in air and no mercury lamps to dispose of at the end of their life.

In the current formulation, the medium contains a hydrophilic aliphatic urethane acrylate solution in water, containing 50% acrylated products. This has a 95% solids content and so is easily diluted with water. Tripropylene glycol diacrylate (TPGDA) acts as a reactive dilutant monomer that also promotes adhesion to substrate, hardness and scratch resistance of the cured layer (Mashouf, 2014). Other additives are used to further increase adhesion to substrate and flow of the medium.

Because of the long wavelength absorption characteristics, which are also better suited to commercially available LED's, acylphosphine oxides are particularly useful for the polymerization of pigmented formulations where irradiation at longer wavelength is desired. This family of photo initiators are used due to the high reactivity of the photo chemically formed phosphonyl radicals that arise from the high electron density at the phosphorus atom. Furthermore, the pyramidal structure of the radicals provide more favourable steric conditions for the unpaired radical site to react with monomers to initiate and propagate the polymerization reaction (Yagci, 2012).

A tertiary amine, N-vinyl pyrrolidinone (NVP), is used in the formulation to help in overcoming oxygen inhibition (Husar, 2014). Oxygen inhibition is due to the fact that molecular oxygen, at ambient conditions, exists as a diatomic molecule with a triplet diradical electronic ground state. Due to these triplet and radical characteristics, oxygen has high chemical reactivity towards the phosphonyl radicals created by the photo initiator, leading to the early termination of the polymerization reaction. (Miller, 2003) Therefore the free-radical photo polymerization reaction that occurs within the formulation can be inhibited significantly by oxygen in the atmosphere. The final ingredients in the UV LED formulation are mattefying silica to reduce the glossiness of the cured medium and the artist's pigment/materials to colour the formulation.

4. CONCLUSIONS

The paper describes methods for segmenting an image using NPR algorithms that can be exported as vector or .SVG documents that provides a set of instructions to drive CNC paths to a painting rig. Philosophically, we believe an image originally composed or acquired as vectors provides a richer description of an image, which would be especially suited to machine production. Through a process of segmentation and edges, fields of pixels are transcribed into many-layered vectors. The NPR algorithms are the starting point to transcribe the vectors into textured brushstrokes using paint and a highly experimental printer rig. The printer rig is capable of applying multilayers of artist's paints that include both traditional and UV curable inks (as described in section 4). The user is able to change the appearance of the layers ie. changes to translucency and viscosity by modifying the paints by hand, as well as change the direction of the brushstroke and the arc of the brush stroke by modifying the software, thus enabling the user to extend a greater control over the multi-layering process.

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E-mails: Carinna.Parraman@uwe.ac.uk¸ Paul3.O'Dowd@uwe.ac.uk, Mikaela.Harding@uwe.ac.uk