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MATERIALISING THE PIXEL

A productive synergy

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Abstract. The composite photoreceptive field of the human eye receives photons emitted from a source and converts this energy into image information within the brain. The internal mechanisms of the contemporary camera imaging technologies represent yet another in a long history of attempts to technically replicate this procedure. The critical difference between the capacity of the human eye to receive quanta events or photons and that of a camera transmitting to a digital display device, rests in how much of the original signal can be recovered. This paper aims to show how the 'information deficit' associated with this technological conversion can be enhanced by the deliberate exploitation and re-arrangement of the camera's image sensor mechanism. The paper will discuss how the mapping of pixel grid geometries and colour filter array patterns at the vastly increased scale of building façades, imparts a materiality to urban form that modifies the visibility and performance of the corresponding virtual screen image. The exploration of the material adaptation of pixel geometries leads to a new technique that extends the working gamut of pixel-based RGB colour space and both establishes an index to develop material performance criteria and modifies the limitations of traditional viewing technologies.

Keywords. Pixels; sensor; CCTV; imaging; array; façades.

1. Introduction

As with past scopic regimes, the workings of contemporary digital imaging technologies use analogies that reflect current scientific theories concerning the functioning of the human eye. This technological analogy represents the photoreceptive field of the human eye as a pixel grid, but as Deering (2005) and

Hérault (2010) reveal, digital displays have a diminished capacity to receive quanta events or photons when compared to the human eye. This is based on the fact that a single pixel covers an angular region of only twenty-five cones in the fovea, meaning the pixel carries significantly less visual information than its human counterpart.

The persistence of the ‘eye’ analogy is made doubly problematic by the way digital imaging technologies determine pixel colour. There are, at present, two standard image sensor types, the complementary metal oxide semiconductor (CMOS) and the charge coupled device (CCD). The digital derivation of colour requires the placement of a gridded array of colour filters over these image sensors. These colour filter arrays, or CFAs[1], which can also take into account variations in hardware specifications and manufacturing quality, effectively screen colour and light from an emitting source. The averaging and approximation associated with the digital conversion of this ‘source data’ always involves a loss of visual ‘data’. This situation is hardly remedied when techniques of interpolation between sensor readings are used to address this ‘visual data deficiency’ because the algorithmic extrapolation of colour and luminosity used in this process remains only an estimate. The inability to capture, recover or re-present the original visual ‘data’ means that these technologies produce outcomes that are both functionally and qualitatively very different from the human eye. In this context, the continuing desire to replicate ‘what the eye sees’ encourages only a conceptual limiting that minimises and ‘normalises’ the visual information field of the technology. Under these circumstances innate technological effects are treated as aberrations, resulting in the erasure of numerous visual effects in the image-making process. For this reason a technological re-thinking of the digital image itself is required: one that, by refuting the analogy of the eye, affords a more nuanced attitude to the technology, acknowledging the innate potential afforded by the mechanical transmission and mediation of the digital image.

Previous work by Matthews and Perin (2011) offers one way in which embracing the innate potential of these digital image technologies represents both new ‘materials’ and techniques for the designer. This research, as a response to the way in which city authorities have co-opted ubiquitous, Internet Protocol camera systems as a vehicle to promote the city, shows how the reception and transmission of imagistic content through these CCTV networks can be used to critically inform the design of new urban form. This work, involving the application of the CFA patterns at the scale of built form, exploits the ‘visual data deficit’ of the CFA pattern to produce aberrant effects that strategically altering the visual hierarchy of the webcam image. This

1 Colour filter array patterns: this abbreviation will be used henceforth in this paper.

modification of the viewing experience by exploiting the formal and chromatic qualities of sensor technologies can be taken further. Therefore, this paper will show, first, how a scalar matching of façade elements to alternative array patterns extends Matthews and Perin's previous work on façade visibility and colour and, second, how an understanding of f-stop intervals of the camera's zoom function can be used to tabulate a range of predictable visual effects. In this way the paper will establish an explicit material relationship between webcam technologies and built urban form that offers a reciprocal and synergistic imaging platform for designers.

2. Investigating image information technology

2.1. EXPLOITING CONTEMPORARY IMAGING MECHANISMS

Lucac and Plataniotis (2005) demonstrate that the operation of the internal camera mechanism establishes a direct relationship between the specific CFA pattern and the image quality received by a digital display device. Other research reveals that a direct scalar relationship between a camera's CFA and façade can be extended to different built scales and locations[2] (Matthews and Perin 2011). Together this work suggests, that if the strategic application of CFA patterns can productively enhance or diminish webcam visibility, then it should also possible to identify a hierarchy of array patterns that can be indexed, tabulated and redeployed to address a range of building design decisions. The principal investigations of this paper, therefore, explore how the traditional translation of data types by imaging mechanisms (in particular, brightness/luminosity and particle data) are directly affected by the use of non-traditional CFA's as building façades. The results of this investigation will then contribute to a broader understanding of how their discretionary application is able to privilege a range of different viewing experiences of urban space that is of consequence both virtually, through the screen, and physically, in actual built form.

2.2. PATTERN ADAPTATION HIERARCHIES

The operational principal of a CFA positions the pixel as the central determinant in the translation of image data. Technically, the camera lens focuses the light from a single point within the camera frame onto a specific arrangement of colour filters placed over the pixel array of an image sensor, to generate a charge proportional to that light.

2 For instance, the CFA pattern, when extrapolated and incorporated at increased scale into the physical pattern of building façades, can either enhance or reduce building visibility over the Internet due to its interference with the camera's operating mechanism.

In this context, the pixel is a single scalar element of a multi-component representation. This establishes a direct relationship between patterning/quality of the received image and the patterning within the CFA. Accordingly, when the charges created by the CFA mirror the pattern of elements within the transmitted image, any scaling of a façade pattern to the pixel resolution will affect its virtual counterpart.

This means the pixel is crucial to both the quality and quantity of data transmitted to any digital display device. Compared to the human optical capacity, which processes twenty five times more information than the pixel, (Deering 2005) the performance of the smallest complete image unit (only subdivisible into, green and blue subpixel components) operates at a far lower resolution. One solution to this is to rearrange traditional CFA patterns into new groupings that simultaneously maximise the translation of image data (He and Li 2007) and minimise the occurrence of problematic effects such as moiré patterns (Klompenhouwer and de Haan 2003).

John Savard outlines numerous pattern arrangement opportunities that could potentially exceed traditional CFA pixel layouts (Savard 2009). Savard's comprehensive detailing of unprecedented combinations, involving breakdowns into secondary RGB colours, underlines how rich an area of investigation this is. Despite the fact that CFA choice, 'critically influences the accuracy of the single-sensor imaging pipeline' (Lucac and Plataniotis 2005, p. 1260), it is surprising this area of research remains somewhat neglected. Surprisingly of the patterns investigated in this paper, only one, the traditional Bayer pattern, has been the subject of any investigation. To quote Lucac and Plataniotis (2005), '…there is no known work addressing the performance issues for other CFA's…in such a comprehensive and systematic way.' (p. 1260) Their investigation of ten different RGB CFA types ultimately proposes that while there is no 'perfect' CFA, that the CFA selection does indeed influence performance of the sensor pipeline, while simultaneously reducing image aberrations.

Clearly, the introduction of more adventurous and non-traditional CFA patterns into façade patterns would divest the pixel of its central role in image production. It would also deliver diversity to city image making by placing these technologies and their content into the hands of the designer. With this in mind, a set of tests was devised as a preliminary 'proof of concept' investigation into the effects façades using non-standard CFA patterns might have on the translation of image data. These patterns, selected because Lucac and Plataniotis (2005) identified them as the most effective (p. 1260), would only extend the list of known effects created when these virtual patterns are used in physical urban space. These results, that exceed traditional capacities of CFA legibility, could then be used to identify, tabulate and organise these effects according to hierarchies using image-based performance criteria. The following details the outcomes of these tests.

3. CFA pattern adaptation tests

3.1. HARDWARE SPECIFICATIONS AND PARITIES

As in the previously cited research (2010), the tests were once again conducted using a Sony SX43E Handycam Digital Video Recorder. The operation of this technology is identical to that of the Sony SNC-RZ50N network camera with the exception of specific operational capacities that were again taken into account when calculating results.

3.2. TEST CONSTRAINTS

- Zoom factor - the test results of interest are between 1x and 26x, which is the area of operational parity between the two camera mechanisms.
- Light source/aperture plane distance is at a relative scale of 1:10. i.e. the 5 metre light source/aperture plane distance in the test correlates with a 50 metre distance in an exterior environment. Likewise, the CFA patterns used are 150 mm^2 to correlate with a typical building façade element of 1.5 m^2.
- The lighting source is a single 30W Par 64 RGB LED (with an output equivalent to the traditional 300W Par 56).
- The tests are conducted in low ambient light conditions to simulate the type of urban night condition that would be available over the Internet camera.

3.3. TEST STRATEGY AND PROCEDURE

Tests were conducted using two types of RGB CFA patterns: those investigated by Lucac et al., based upon their ubiquitous deployment within the single-sensor imaging pipeline; and two other modified RGB patterns, one based on the traditional Bayer array pattern, and the other devised to remove the dominant 'R' component of the pattern. The latter pattern also comprises two single vertical strips to test against the concept of the efficacy of 'pseudo-random' patterns (Fillfactory 2010).

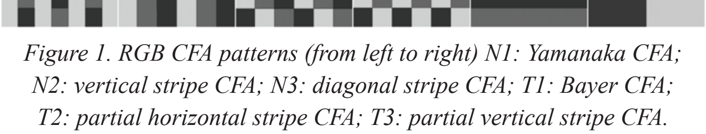

Figure 1. RGB CFA patterns (from left to right) N1: Yamanaka CFA; N2: vertical stripe CFA; N3: diagonal stripe CFA; T1: Bayer CFA; T2: partial horizontal stripe CFA; T3: partial vertical stripe CFA.

The patterns were applied as a transparent colour film to a 3 mm acrylic base and placed in front of a single LED lamp to simulate the type of interior lighting conditions that would operate at night within an urban context. The camera was then placed at a distance of five meters from the light source. Acting as a scaled approximation of the standard Internet camera viewing distance from the image source, this enables specific or aberrant features of the recorded image to be correlated and tabulated in accordance with the performance of the camera's zoom or f-stop increments. It was determined that the assessment criteria to be applied to the performance quality of these patterns should focus on their ability to produce higher legibility in façade applications. These criteria were luminance emission levels, cited as the highest acuity for the human eye (Fillfactory 2010) and data or particle transmission levels, to observe the comparative quantum of digital information. The test results were processed using the luminance visualisation and measurement function of *ImageJ*[3]and, subsequently, a combination of a binary converter and particle assessment function. Procedurally, video footage of stills falling within the appropriate f-stop range were imported as a 'stack' of discrete image units and then processed to determine both luminance and particle criteria. In the latter case, the images were converted using the Floyd Steinberg Dithering algorithm, which converts images into binary form so that they can be counted and measured.

3.4. TEST 1 – LUMINANCE TESTS

3.4.1. Results

The individual patterns were labelled N1; N2; N3; T1; T2; and T3 (Figure 1).

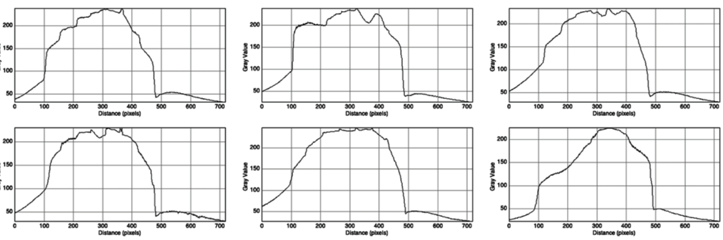

Figure 2. Comparative luminance emission levels of patterns N1-N3 (top row) and T1-T3 (bottom row) between F1.8 and F3.8.

- The luminance levels of pattern T2 (the incomplete horizontal Bayer pattern) exceeded the luminance levels of all other patterns (Figure 2).
- The luminance levels of patterns N2 and N3 were the highest of the CFA patterns currently in use, followed by that of patterns T1 and N1 (although the

3 *ImageJ* is open-source JavaScript medical imaging software.

lower result for both N1 and T1 might potentially have been influenced by the inclusion of more green due to the repetition of the pattern within the selected viewing frame (Figure 2).

- The luminance level of pattern T3 was the lowest (Figure 2).
- The maxima (brightest spot) count was the highest for patterns N1 and N2 followed by T3 (with the lowest luminosity level) and then T1 and T3 (Figure 3).
- The maxima (brightest spot) count was the lowest for pattern T2 (which had the highest luminosity level, Figure 3).

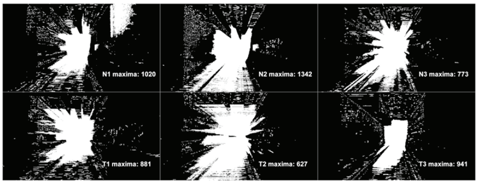

Figure 3. Comparative maxima spot counts of patterns N1-N3 (top row) and T1-T3 (bottom row) between F1.8 and F3.8.

- Chroma visibility in all patterns operated as follows: on the inward zoom, red was the first colour to become completely visible at f2.6, followed by blue at f3.0 and finally green at f3.2. On the outward zoom, the same order of visibility was apparent, however, the visibility period was extended with green remaining completely visible until f2.8, blue until f2.4, and red until f2.

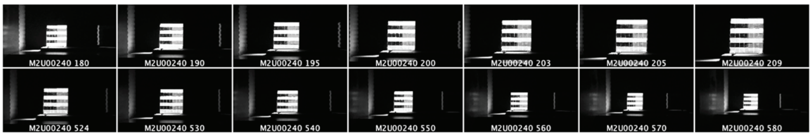

Figure 4. Chroma visibility progression for according to camera f-stop intervals for CFA pattern T2.

3.4.2. Observations

- Pattern colour distribution and combination influences visibility: red is the most visible followed by blue while green is the least visible. Any colour combination that includes red advances visibility, particularly if it is just one other colour (although a combination of red and green was not tested here). The combination of blue and green is the least visible.
- Pattern orientation influences visibility: vertical stripes are the most visible, followed by the diagonal and then vertical except when red is present.
- Patterns with more evenly distributed luminance information have higher visibility (Figure 5).
- Maxima (brightest point) occurrence is higher in the vertical stripe pattern.
- There is a difference in the progression of colour visibility between the inward and the outward camera zoom journey.

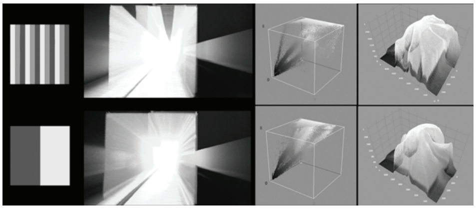

Figure 5. ImageJ visualisations of luminance distribution for N2 (top) and T3 (bottom).

3.5. TEST 2 – PARTICLE DATA TESTS

3.5.1. Results

- The data count for patterns N1 and N2 was the highest (based on the vertical stripe), followed by T1 and T2 (checkerboard and horizontal stripe).
- N3 transmitted significantly less data than the above.
- T3 transmitted the least data (undifferentiated double vertical stripe)

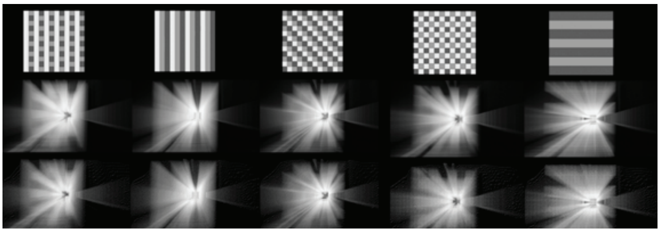

Figure 6. ImageJ montage of (top row) CFA patterns; (second row) standard deviation (variation in pixel distribution) for CFA image stack ;(third row) translation of standard deviation into binary information using Floyd Steinberg Dithering algorithm; and (bottom row) ImageJ particle data count for all patterns.

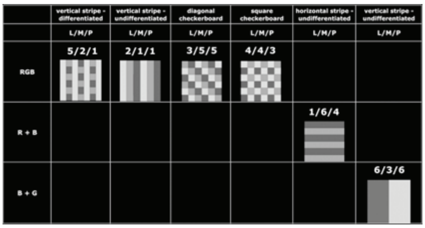

Figure 7. Index of material performance according to colour combination and pattern showing relative luminosity (L), maxima/brightness (M), and particle data (P) values.

3.5.2. *Observations*

- These results correlate with the luminosity and maxima (brightest spot) readings indicating that image legibility is affected by pattern orientation, distribution and colour combination.

4. Conclusion

While these results represent a preliminary investigation into the adaptation of CFA patterns as formal constituents of building façades, it is evident that this can be strategy used to manipulate building visibility within a virtual context. Although the thorough investigation of all permutations of RGB CFA's remains incomplete, these results indicate a direct relationship between façade pattern and the internal permutations of these patterns: specifically distribution, orientation and colour combination. Moreover, these results can be indexed to formulate an operative palette and hierarchy of formal visibility that the designer can reference and incorporate into building façades.

Clearly this work shows that the manipulation and scaling of façade materiality to pixel arrangements, when transposed at different scales, results in unprecedented visual effects. In establishing a functional link between digital viewing technologies and the material urban environment, one opens a synergistic imaging platform where the technologies of the pixel are no longer a proprietorial concern but can be adapted to actively engage the Internet viewer. While these results remain conditional, the matching of façade to CFA patterns clearly has formal and material consequence that impact on urban images. Furthermore, the linking of pattern to light and colour means that one can indirectly inform interior spatial, and hence programmatic, organisation. Importantly, this strategic and tactical use of image technology can only occur by dispensing with the dual notions that the camera is an eye and that these technological effects are 'aberrant'.

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