



## 2D Barcode Sub-Coding Density Limits

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### Keyword(s):

2D barcodes; sub-coding; high resolution;

### Abstract:

The use of 2D barcodes is becoming increasingly popular and is driven by both the added payload (data carrying capacity) that is provided over 1D linear codes and the fact that the majority of current Smart-phones are capable of reading them. While it is desirable to associate a forensic print signature with the outline of the 2D barcode, the high resolution required to image the stochastic microscopic structure typical of the printing process makes it difficult, expensive and bulky to achieve the field of view required for reading a 2D barcode of sufficient payload that can independently be read by a hand-held smart-phonedevice. One solution to this problem is to use a technique of 'subcoding' (introduced by Omniplanar) whereby an inverted mark smaller than the size of an individual barcode module (or 'tile') is placed within each module and the position of the mark(s) within the module provides the ability to code data. This increase in coding density enables the complete contents of the barcode to be repeated in a sub-region. This results in the field of view of the high resolution reader being reduced significantly, whilst maintaining the ability for both the forensic authentication and extraction of the barcode identity to simplify the forensic referential lookup. However, there is a limit to the sub-coding density, as it ultimately affects the primary barcode reading ability through a reduction in contrast. This paper investigates the density sub-coding payload until it affects the primary payload of the 2D barcode. We also explore if there are sensitivities to the placement of the sub-coding mark within a module and what effect dot gain has on the design of the sub-coding scheme.

# 2D Barcode Sub-Coding Density Limits

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## Abstract

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*This paper investigates the density sub-coding payload until it affects the primary payload of the 2D barcode. We also explore if there are sensitivities to the placement of the sub-coding mark within a module and what effect dot gain has on the design of the sub-coding scheme.*

Keywords: 2D barcodes, sub-coding, high resolution; forensics; anti-counterfeiting; print parasitics

## Introduction

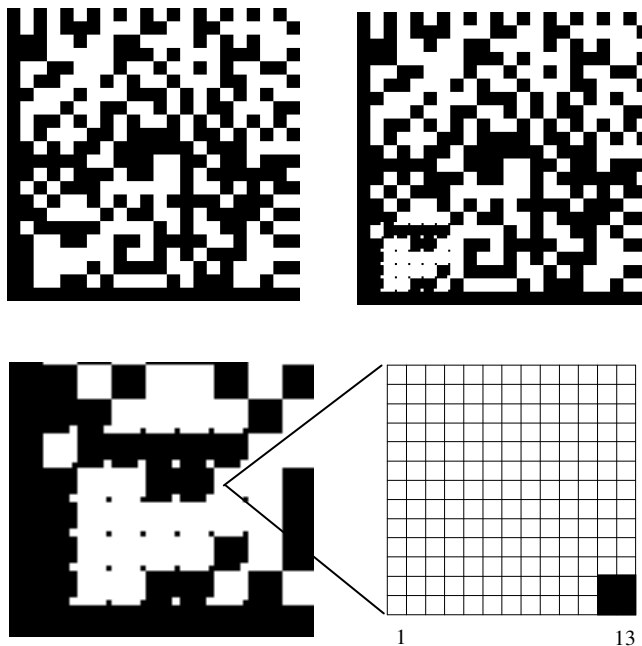
There is a cost of imaging a large area at high resolution. We have previously shown [1] that it is possible to achieve robust forensic identification of printed document, labels etc using imaging devices based on a Dyson relay lens and low cost CMOS image sensor (Dr CID) We have shown that this approach is scalable to larger instantiations however the physical size of the solution increases as well as the cost of the image sensor.

While we have previously shown that it is possible to use any form of character or glyph as a forensic mark (provided it has sufficient discriminating shape to allow it to be modeled and accurately located in an image) it is highly desirable to associate the forensic signature that is recovered from the outline of the forensic mark with serialization information recovered from the same image. This obviates the need to search through a, potentially very large, database of forensic marks to validate or repudiate the

current observation. Rather the serialization data can be used as an index into the database to allow direct comparison of a forensic signature recovered in the field with one stored in the database at the time of print or shortly thereafter.

One way this can be done is to collect the forensic signature from the fixed 'L' shaped outline of the 2D Datamatrix symbology. However such a 2D barcode with a payload sufficient to encode a unique 96 bit (Global Trade Item Number (GTIN) compliant [2]) identifier and with a module (tile) size of approximately 0.5mm to make it readable by the majority of auto focus smart-phone readers (which would make it useful independently of Dr CID). This results in a field of view (FOV) requirement in excess of 10mm which is significantly larger than the 4.8mm of a typical Dr CID with a low cost 3MP 3.2µm pixel sensor. It is possible to extract a usable forensic signature from a smaller section of the edge of the printed 'L' at the corner of the barcode but this would not allow us to recover the barcode payload using the Dr CID device.

Rather than increase the size and cost of the high resolution reader in order to image the whole barcode, we adopt a technique of 'sub-coding' [3]. This is based on placing smaller coding marks within the module as shown in figure 1. The secondary coding is achieved by the variable physical placement of the sub-codes within the module. Dr CID has the resolution to detect these as the accuracy is print limited [3] and not imaging limited however, they need to be small enough so as not to interfere with the requirements of the 2D Datamatrix itself.



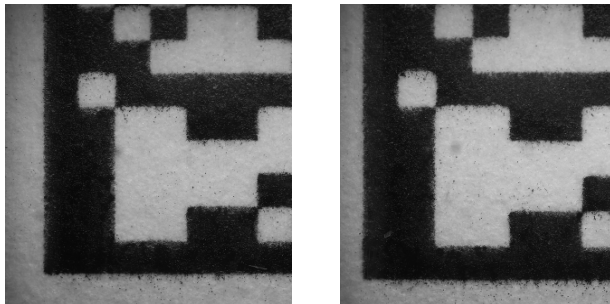
**Figure 1.** Sub-coding approach 2D barcode merged with sub-coding over 6 x 6 modules on a 600dpi grid of 13 x 13. Example is a 2x2 sub-tile - see text for details.

In order to meet the requirements of the forensic reader, figure 1, (top right & bottom left) shows the corner of the 2D barcode framing that will be used for extracting a forensic signature and a region of 6 by 6 modules (plus one for the barcode framing 'L') that will be used for the sub-coding. The total FOV requirement is a square of 7 x 7 barcode modules (at 0.55mm) plus a minimum of 1 module for a quiet zone/margin which in total is 4.4mm and suitable for the current low cost Dr CIDs. The 0.55mm module is then divided into 13 off 600dpi sub coding spaces as shown in figure 1 (bottom right).

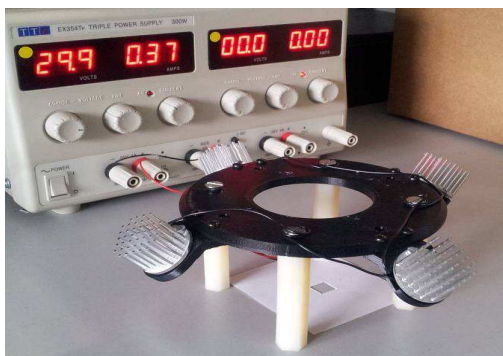
## Experiments

### A. Calibration

The first test was to ensure that the generation and printing of the test structures resulted in an uncorrupted output from a typical office LaserJet printer, as the primary interest is in document tracking. A test barcode was created at the pixel level in Photoshop as a bitmap and then printed directly from the application on an HP P4515 office printer. This was checked against the same structure printed as a postscript file via Ghostview. As well as inspecting with Dr CID (figure 2) which resolves at ~ 7000dpi (greater than 10 times the 600 dpi sub-coding pitch, the images were also captured with a 3MP Aptina development camera and processed using 2D Technology Group's (2DTG) [4] online barcode processor that reports the 2D Datamatrix quality parameters (figure 4) including symbol contrast and modulation. There were no discernible errors in both printed outputs and all the parameter checks passed. The rig for capturing consistent images was built to conform to the ISO/IEC15415 /ANSI standards and is shown in figure 3.



**Figure 2.** Photoshop (BMP) left and Postscript (right) outputs imaged with Dr CID



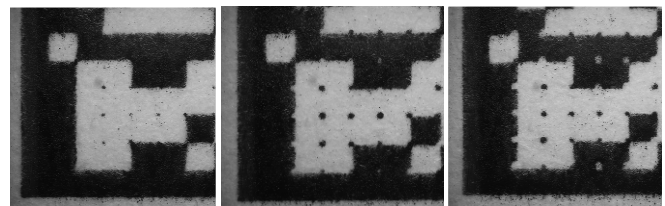
**Figure 3.** Lighting and camera support rig – illumination is provided by 4 high power LED's aimed at 45degrees to the central image zone.



**Figure 4.** Laserjet ground truth - 2D Technology Group online decoder

### B. Printer limitations/dot gain & pre-compensation

Printing singular small structures is usually limited below the resolution of the printer. As can be seen from figure 5 (left), printing 600 dpi inverted tiles is not reliable and in particular dot gain of the small white tile within black totally fails. Thus, all the tests will be limited to a smallest sub-tile of 2 x 2 tiles (middle). Because of the dot gain within black due to printer and substrate errors, this will be structurally pre-compensated [5] to ensure correct final output (right).



**Figure 5.** 600 dpi limitations, dot gain and pre-compensated output

### C. Devices

The following devices will be used to test for readability of the different sub-coded 2D barcodes.

i) Symbol DS6608 dedicated hand held barcode scanner ii) iPhone 4 (5MP) with NeoReader decoder application iii) Samsung Galaxy SII (8MP) with ZXing decoder application iv) Aptina 3MP development camera with 2DTG online decoder, v) iPhone 4 with 2DTG and vi) Samsung Galaxy SII with 2DTG.

### D. Error correction

The first test was performed using the full 2D barcode in figure 1 with progressively larger sub-tiles (from 2 off 600dpi increments on a side all the way to 13 i.e. the module is inverted), located in the bottom right corner of figure 1 (bottom right) and added into the 6 x 6 module region in the lower left corner. As

might be expected, all of the barcodes were read with all of the readers. This is due to the robust error correction built into the Datamatrix codes and the 2DTG online parameter output reported up to 70% ECC usage with the 13 pixel fully inverted sub-tile. Our approach for the rest of the experiments was to implement the sub-coding over the whole barcode (except the fixed pattern). This allowed us to find the threshold for readability as the onset of the corruption resulted in a global failure of both the data and error correction. To aid in the creation of the barcodes we will use a smaller 10 by 10 module Datamatrix.

### E. Sub-Coding size threshold

Figure 6 shows sample images of the smaller code with full sub-coding and the placement on the sub-coding 600dpi grid. Left is 2x2 600dpi pixels middle is 6x6 and right is 9x9 pixels.

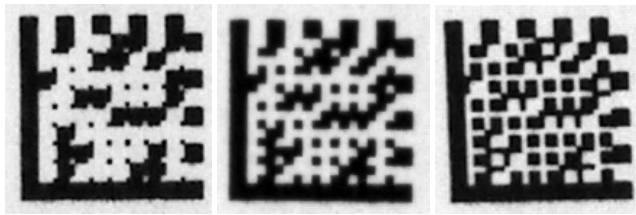


Figure 6. 10x10 module barcode sub - coding

The results for this are shown in figure 7. The point of interest is where any reading starts to fail, so the limit was found to be a 5 pixel sub-coding tile size when using the 2DTG decoder and any of the cameras. The actual failure mode is not immediate – the decoder continues to work for one or two larger sub-coding tile sizes. However, it is not reasonable to propose barcodes that are not fully compliant.

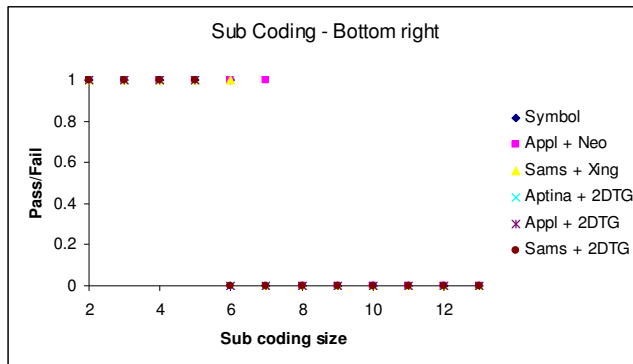


Figure 7. Sub-coding threshold to tile size placed in a corner

### F. Sub-Coding placement

The same test as in E was run, but with the sub-coding tile located in the centre of the barcode module. The results are shown in figure 8 and reveal a particular sensitivity of one of the decoders to this central placement zone. The 2DTG decoder fails for all sub-tile sizes whereas the Symbol, iPhone + Neo and Samsung + ZXing start to fail at 5 sub-tile pixels which are still less than for the corner placement.

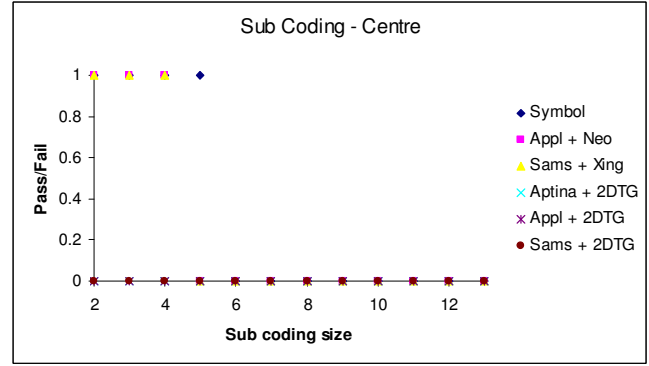


Figure 8. Sub-coding threshold to tile size placed in a corner. Note all of the 2DTG decoder approaches failed to read at all.

### G. Central placement sensitivity

This experiment explores the sensitivity to central sub-coding tile placement. Sub-coding tile sizes of 2 to 5 pixels were placed in the centre and then progressively moved towards a corner (figure 9).

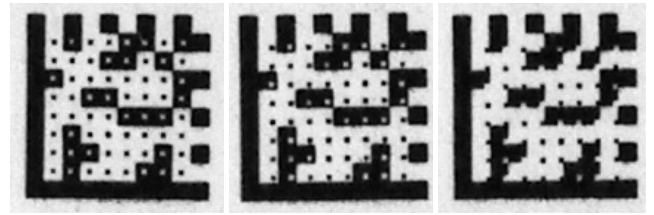


Figure 9. Central sub-coding placements of a 2x2 sub-code – centre, 2 pixel offset, 5 pixel offset.

For the 2 and 3 600 dpi pixel dimension sub-tiles, the threshold is 3 pixels offset from the centre i.e. the outer 3 pixel rings are without error and for the larger sub-tiles of 4 and 5 these reduce to 2 and 1 respectively.

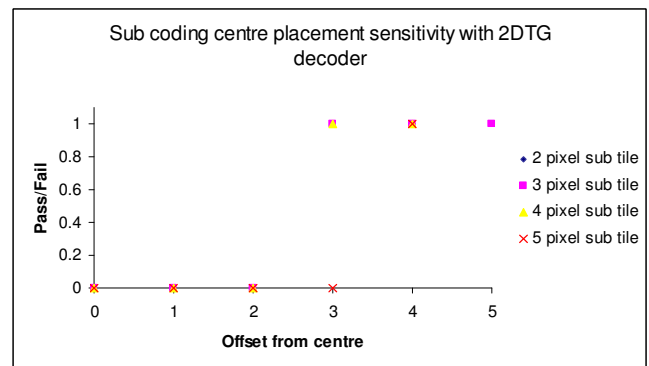


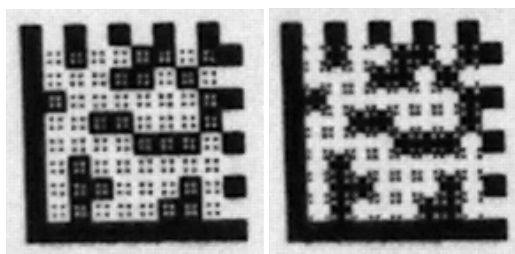
Figure 10. Central to corner sub-coding results

### H. Further tests

Further tests were run to check for other sensitivities. The issue of central placement of the sub-coding elements was tested by offsetting orthogonally to the edge of the module rather than

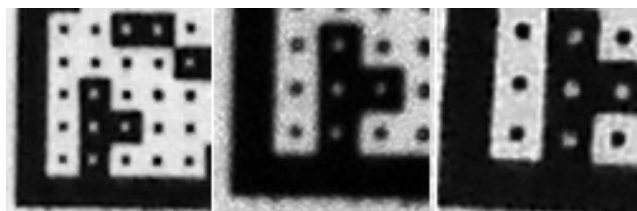
diagonally to a corner. These results closely match the corner results above in figure 10 (data not shown). Possible pixel-related adjacency issues have been tested using the corner tests. The boundary of the barcode tile is clearly broken by the sub-coding, and there are several regions in the sample barcode where the subtraction of black and addition of white etc are adjacent.

We have also tested placing multiple sub-coding dots within a module (figure 11) to test if there is an area limitation. Whilst the Symbol, iPhone + Neo and Samsung + ZXing can read all of the displacements of 2 to 5 from the centre with 4 corner marks, the 2DTG decoder threshold drops from a threshold 3 to 5 pixel offset. It does still decode with ECC of 40% used and still obtains a full modulation score for offsets of 3 and 4.



**Figure 11.** 4 sub-coding marks per barcode module. Left 2 pixel offset from centre and right 5 pixel offset.

The different camera resolutions have little influence on the results from the 2DTG decoder with the trends being visible across all 3 different resolutions.



**Figure 12.** Camera performance comparison – Aptina 3MP, iPhone 4 (5MP) & Galaxy II S (8MP)

## Discussion

The results illustrate that the accuracy of the barcode decoders is affected by multiple factors. In addition, there are differences between the 2DTG decoder and the other decoders (NeoReader and ZXing), but little difference in the different cameras. Not surprisingly, the size of the added sub-code marks is limited by the contrast/modulation and other factors in the decoding. Interestingly, the placement of the sub-codes has a rather profound influence on the decoding. We propose that this latter dependency is due to the frequency content of the image. Specifically, central placement of the sub-codes is optimally aliasing or disruptive to the 2D FFT otherwise dominated by the original (larger) modules in the 2D barcode.

If the sub-coding is constrained to the outer region of a barcode module as figure 10 shows is 100% readable for all devices tested, a 3 pixel sub-tile can contain 40 coding positions for the outer band, 32 for the next moving inwards by one sub-coding pixel and 24 for the third. Thus the total number of coding

positions is 96 which equate to a little over 6 bits per 2D barcode module. When this is multiplied by the 6x6 modules that contain the sub-coding the total number of bits is in excess of 216 bits. Given that this is available for data and error correction as the framing is already provided by the 2D barcode corner then it is feasible to contain a copy of a 96bit GTIN or similar in this smaller region. This density of 216 bits in a 4.4mm on a side square equates to 7194 bits (900bytes)/in<sup>2</sup> with binary levels. (Villán et al. [6] provide several multilevel (grayscale or color) barcode approaches providing a greater coding density of up to 2400 bytes/in<sup>2</sup>).

## Conclusion

In comparison to other approaches (e.g. staggered barcodes [7]) sub-coding adds additional content to existing modules rather than logically re-arranging two or more modules. The payload density of these additional marks is much higher than the 2D barcodes themselves e.g. from 2000 to 7000 bits/in<sup>2</sup> for a 0.55mm barcode module enabling a unique identifier to be provided in a small sub-region

This paper was originally conceived in order to determine the optimal means of hiding additional information in a readable, standards-based 2D barcode. We have shown that this is possible however, if compatibility with mainstream readers is required, then there are particular considerations that need to be observed with regard to the placement of any sub-coding mark in order not to disturb the native barcode data.

The adding of information appears to benefit from a more stochastic distribution of the sub-codes in order not to be detected by any frequency detecting decoding. This is advantageous to adding serialized (i.e. random, alphanumeric, etc.) content. In addition the error correction for the sub-coding can take both the stochastic distribution into account as well as being optimized for the particular printer/substrate artifacts.

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## Author Biography

*Guy is the hardware lead for security printing and imaging project within HP Labs. Guy joined HP Labs in 1996 and has worked on several projects that became successful products such as class leading CMOS image sensors, cameras for PDA's. Guy is always keen to deliver innovative technical solutions and he has more than 12 granted patents and more than 23 pending. Guy is a member of the IET and a Chartered Engineer (UK equivalent of Professional Engineer).*