Context-Free Decoding of High-Density 2D Bit Fields with Alias Disambiguation

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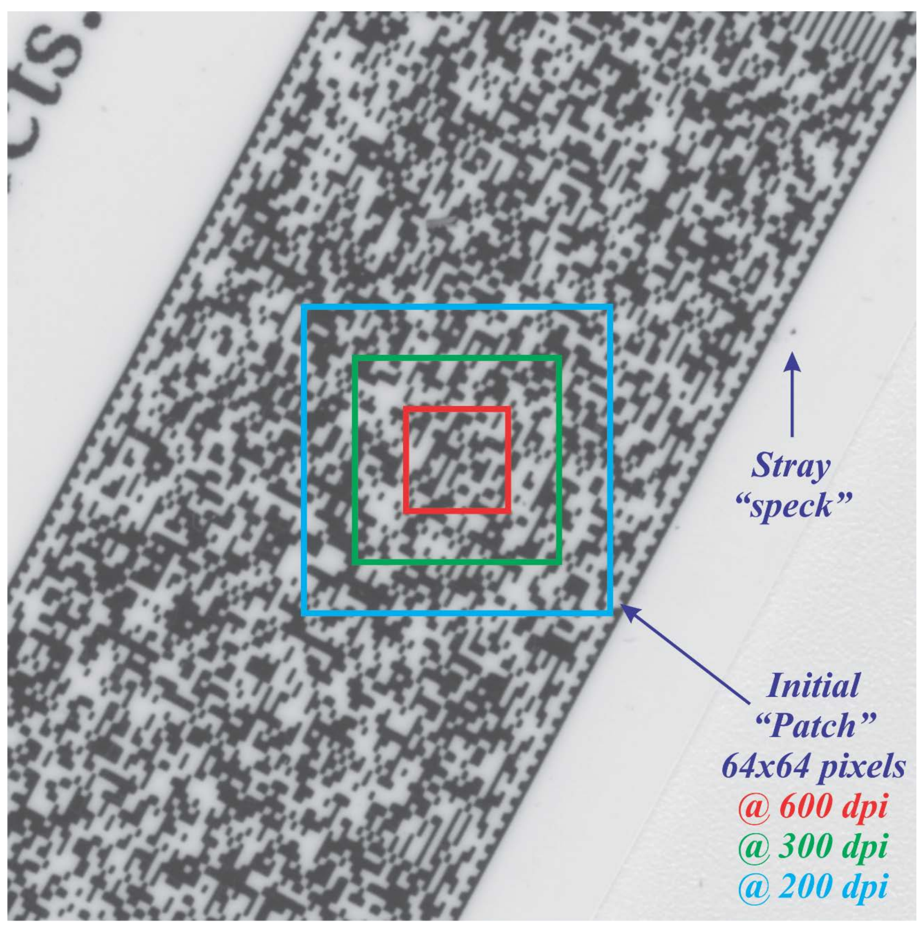


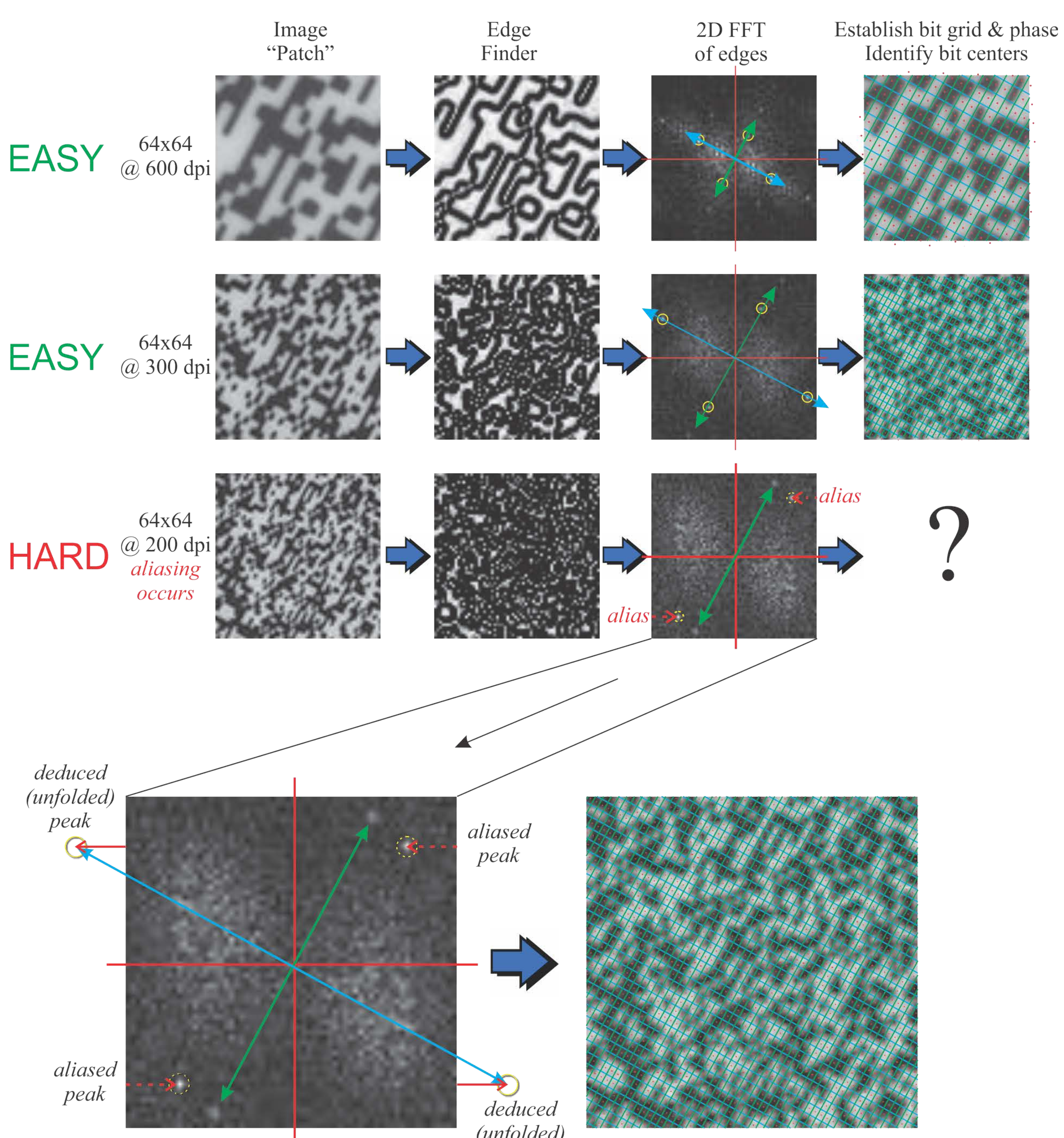
Sample of 2D rectangular-array code
Bit Grid Spacing is 0.010" x 0.015"

PROBLEM:

Conventional decoding techniques tend to operate exclusively in the space domain and often rely on code-specific "finder features," ECC, high-resolution imaging, image resampling (a "lossy" process), encoded data "clues" and low code density relative to image resolution (see EASY examples below). This limits the amount of information that can be reliably encoded into a given area.

RESEARCH OBJECTIVES:

- Recover randomly-oriented 2D bit fields without resampling, without reliance on finder features, and without dependency on encoding or data content
- Decode at image densities that produce aliasing of primary grid frequencies – *alias disambiguation* (see HARD example below)
- Provide linear code density improvement of 1.5:1 to 2:1 over conventional techniques, resulting in an increase in data density per unit area of 2.25:1 to 4:1



Rule-based disambiguation and "unfolding" of aliased grid frequencies

Establish bit grid & phase
Identify bit centers

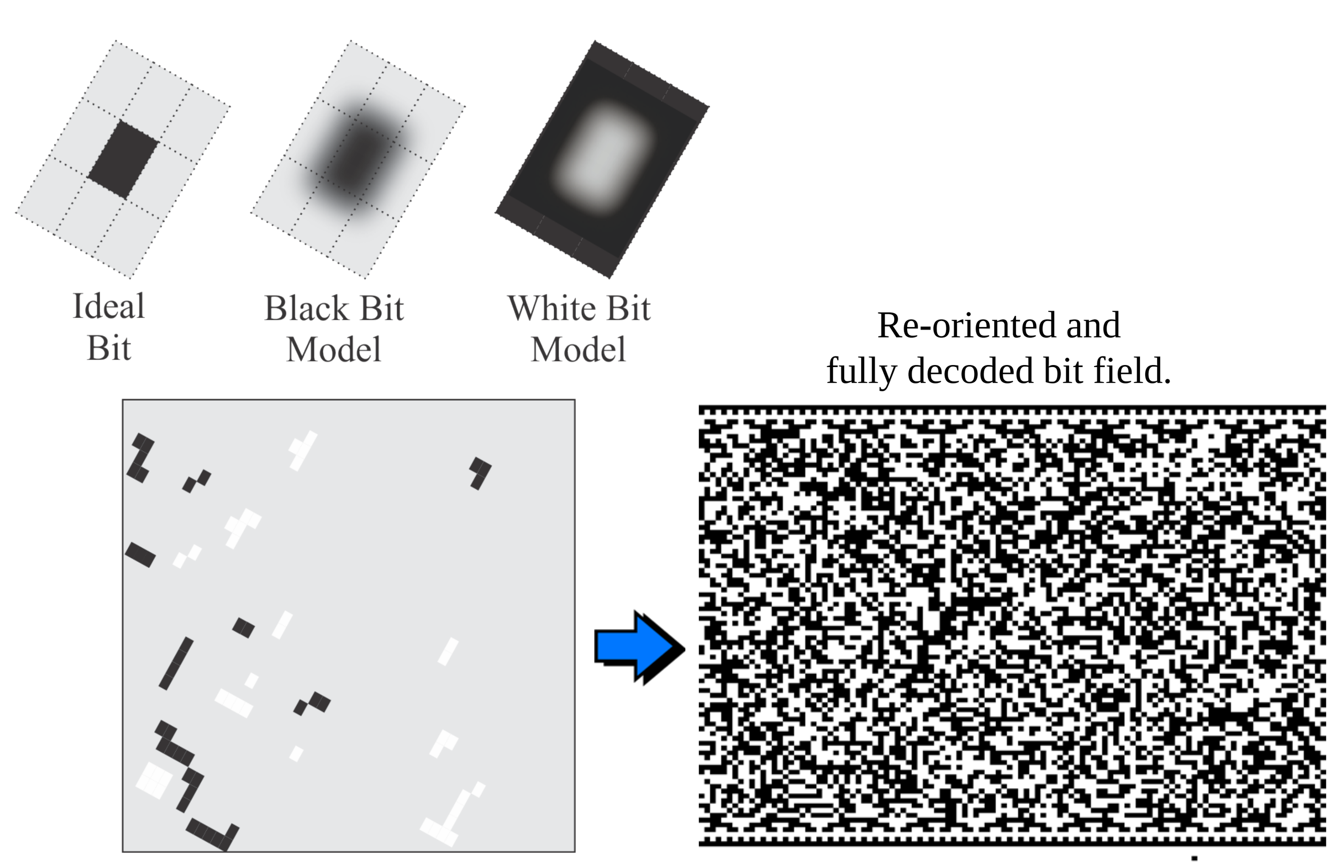
Establish Bit Grid Metrics, Identify Bit Centers

- Camera/Scanner MTF, point spread-function (PSF) and ink-spread affect apparent bit shape and spatial frequency content
- Random bit fields exhibit no periodicity. Edge detection exposes bit grid periodicity

1. Select a convenient-size image "patch" within the code and perform edge detection.
2. Take 2D CFFT (complex FFT) of edge-detected "patch"
3. Ignoring small band around DC, identify primary grid peaks. Determine if code is "EASY" case first. If not:
4. Perform rule and geometry-based disambiguation of aliased peaks and "unfold" to determine location of "true" grid peaks.
5. Take complex geometric center of small area in CFFT surrounding each grid peak
6. Inverse CFFT of values (5) to get grid spacing and phase
7. Use grid data from multiple "patches" throughout image to refine grid over large spans, identify distortions, etc.

NOTE: Process left/top and right/bottom edges separately and merge results after grid extraction to avoid phase cancellation of grid peaks in 2D FFT due to edge-spread of bits in image

Bit Modeling and Decoding



High-Confidence Bit Value Assignments

Note presence of "speck"
Identified above in original image

1. From 2D FFT analysis above, estimate system MTF, PSF and ink spread, and develop a "Bit Model" describing the extent of a bit's influence on grayscale values of surrounding image pixels.
2. Determine extent of code by searching for "quiet area" around code
3. Apply bit model across code image, correcting each bit-center grayscale value for the influence of neighboring bits. (Initial correction based only on grayscale values, later corrections take advantage of known bits.)
4. Assign bit values for high-confidence bits (initially, this will tend to occur in large white or black areas where there is little ambiguity)
5. With new, known bit values in place, readjust bit-center gray values and assign additional high-confidence bit values.
6. Continue assigning bit values and improving bit-center grayscale estimates until all bit values have been assigned

Conclusion

This technique provides excellent, low-error-rate recovery of raw, uninterpreted 2D bit fields, even at density and resolution combinations that produce significant aliasing. The technique is well-suited to a wide variety of 2D codes (PDF-417, QR Code, Aztec, Datamatrix), even hexagonal codes (Maxicode)

References

1. Gaur, Priyanka, and Shamik Tiwari. "Recognition of 2D Barcode Images Using Edge Detection and Morphological Operation." *International Journal of Computer Science and Mobile Computing* 3.4 (2014): 1277-1282
2. Pârvu, Ovidiu, and Andrei G. Balan. "A method for fast detection and decoding of specific 2d barcodes." *Proceedings of the 17th Telecommunications forum TELFOR*. 2009.
3. Chandler D.G., Batterma E.P., and Shah G, "Hexagonal, information encoding article, process and system" U.S. Patent 4,874,936, issued Oct 17, 1989
4. Falas, Tasos, and Hossein Kashani. "Two-dimensional bar-code decoding with camera-equipped mobile phones." *Pervasive Computing and Communications Workshops, 2007. PerCom Workshops' 07. Fifth Annual IEEE International Conference on*. IEEE, 2007.