Toward fluid, mobile and ubiquitous interaction with paper using recursive 2D barcodes

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ABSTRACT

This paper describes a novel 2D barcode approach for interaction with paper at varying distances using camera-enabled handheld devices. Intended for use with large paper formats such as maps and posters, barcodes are presented in a grid, providing location and orientation data across the entire area of the paper. The barcodes are reflective in the near-infrared range, just outside the visible spectrum. To permit interaction from varying distances, the barcode pattern is recursive: barcodes at a lower dimension constitute 'bits' of data in higher-dimension barcodes. An algorithm permitting fluid interaction is discussed, as are details specific to operating in the near infrared range.

Keywords

2D barcode, digital paper, augmented reality.

1. INTRODUCTION

Ubiquitous, mobile interaction using handheld devices with static paper artifacts such as maps and posters has been limited in terms of the required distance between handheld and artifact. Systems have been demonstrated which limit interaction to the near field [1], or extreme near field [2,3]. Alternately, 2D barcode systems [4,5] also constrain relative distance, as they require a persistent fix on the barcode. Other technologies exist that do permit fluid interaction at a range of distances from the paper artifact [6,7], however this is accomplished with hardware infrastructure that is not generally appropriate for wide scale deployment, outdoor or mobile use.

The technique described in this paper permits interaction at a range of distances, and requires only a smartphone camera. A recursive grid of 2D barcodes is printed on paper using ink that is reflective in the near-infrared range.

2. USING INFRARED

In order to avoid occluding important details in an information-dense document such as a map, it is necessary that some sort of steganographic technique be used to hide the barcode glyphs. This could be accomplished in a manner similar to digital image watermarking where, for example, the least significant bits of red, green, and blue channel colours are used to store the underlying data. Unfortunately, most digital watermarking techniques are unable to withstand the analog to digital conversion process or the distortions caused by photographing using a handheld device [8].

The properties of the sensors in digital cameras, however, provide for an alternative approach using another mainstay of steganography: invisible ink. Many CCD and CMOS arrays are sensitive to transmission in the near-infrared band, which falls between wavelengths of 700 to 1200 nm. By removing internal infrared cut-off filters or adding infrared-only filters, they can be coerced into seeing that which the human eye cannot. This then provides the possibility of using infrared-reflective ink as a method of annotation hidden from the viewer.

Although the use of IR ink is not entirely novel – for example the Anoto digital paper system uses a special pattern printed on regular paper to digitally record pen marks [2], it is far from well-explored. The Anoto system represents a fairly ideal situation where the ink is illuminated by infrared LEDs in the pen. We intend to rely on ambient lighting, using an infrared filter to isolate the hidden glyphs. Discussions with experts in the use of infrared suggest that the approach is feasible [16], but still requires further investigation as not all light sources provide the same amount of emissions in the near infrared. Fortunately, ambient temperature will not be a concern, as such black body radiation occurs mostly in the far infrared. As well, it is important that the regular inks used in printing the document be mostly transparent in the infrared spectrum in order to provide a clear image for processing.

3. BARCODE DESIGN

Each barcode is a simple grid of squares, each 'set' (filled in) or 'unset'' (left blank). This is similar to many existing 2D barcode designs including QR Code [9]. However, information density is not a primary concern in our design: barcodes need to simply distinguish themselves from other codes that exist on the same paper artifact. This permits a barcode pattern that is highly regular and straightforward to process, much like codes used in augmented reality applications [10,11].

At the bottom of each grid is a control bar, which is used by the vision algorithm to situate and understand the barcode (figure 2). Each control bar has a blank section on its right side to assist in determining orientation; the relative size of the blank section to the entire control bar also indicates the bit density and dimensions of the barcode itself. The value represented by each barcode identifies its location on the paper, much like the dot pattern in Anoto [2]. The size and orientation of the bar-code relative to the camera also provides a visual fix that can be used to correctly position overlay data on the handheld.

Because barcodes are printed in a grid, overlay data can be generated when the camera is quite close to the paper. Furthermore, to permit interaction from a range of distances, the barcode pattern is recursive (see figure 1). This further constrains the barcode design: barcodes need to be highly regular, and placed close to each other. This second constraint does increase the required information density of each barcode. In the recursive pattern, individual barcodes themselves represent squares in a larger grid pattern (a larger barcode), with its own control bar. All barcodes on the same 'level' share the same dimensions, orientation and bit density. In order for a barcode to represent a single square in a larger barcode, it must be either very sparse or very dense.

Unlike the Anoto dot pattern, which utilizes slight variations in relative position, this approach limits the range of values that a barcode can represent, but the range available is more than adequate for poster-sized grids. For example, if the size of the grid on the lowest level barcode is 5x5, and we permit up to 2 squares to be on for sparse grids, and up to 2 off for dense grids, we have (1 + 25 + 25 choose 2)*2 = 652 possible values, and e.g. a 25x25 grid. Barcodes should be small enough that the camera will be guaranteed to capture at least one barcode at the closest desired range of interaction (this will be the case if the region captured by the camera is >= 3x the height of the barcode. We require 3x due to spacing between barcodes and the presence of control bars). If each barcode is 2cm^2, this permits a poster's active region to be 50cmx50cm. This can be increased by increasing the bit density of the lowest level barcodes and/or increasing the number of bits that can be set (sparse) or unset (dense). For example, changing each barcode to have 36 bits (6x6) and permitting 3 bits set or unset permits a 124x124 grid.

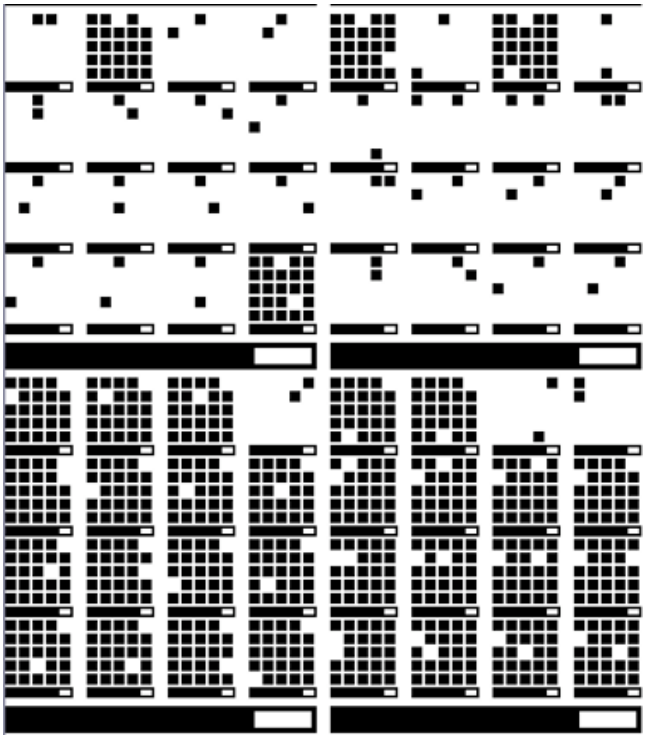

Figure 1. the recursive 2D barcode pattern. In this example, the lowest level barcode is a 25-bit grid. The barcode in the top left has two bits on the top row set. Each barcode itself constitutes a bit in a higher level barcode. Here, the next barcode level is a 16-bit grid. The second-level top left barcode has one bit set in the top and one in the bottom row. Second-level barcodes can in turn constitute bits in a third-level barcode if desired. Shown in this example are 4 third-level barcode 'bits', 2 unset and 2 set.

The placement of each barcode must be controlled such that they comprise barcode bits on a larger scale. This is easily accomplished by ordering barcodes according to their binary value, and flipping the bits of barcodes that need to represent a 'set' or alternately 'unset' bit in the higher dimension. Higher-dimension barcodes are intended for when the camera is at a distance such that the smaller barcodes can't be accurately read. The readable range of smaller dimension and larger dimension barcodes intersect considerably, however, making it possible to achieve smooth tracking when moving the cameraphone between ranges.

Figure 2. A barcode control bar. The placement of the white region indicates the orientation of the barcode. The size of the white region relative to the size of the black region indicates the 'level' of the barcode, which establishes the barcode's dimensions and bit density.

3.1 Tracking motion parallel to the paper

Once a single barcode is identified, the algorithm knows where all other barcodes are relative to this barcode. Motion is captured by determining the change in position of the tracked barcode's control bar between frames. Because the pattern is extremely regular, achieving this using the control bar alone is problematic. The algorithm incorporates a "closest control bar" heuristic as follows:

1. identify the control bar that is closest to the position of the tracked barcode's control bar in the previous frame
2. assume that this is the control bar of the tracked barcode – adjust recorded position and orientation of cameraphone accordingly.
3. If the bit pattern of this barcode is not completely contained within the captured image, select a barcode in the captured image that is in the opposite direction from the observed change between frames (note that the value of this barcode can be predicted), otherwise, continue to track the current barcode
4. Verify that it is the expected barcode by recognizing the bit pattern. If it is a different barcode, update the position data.

3.2 Tracking motion toward/away from the paper

A record is also maintained of the previous size of the tracked barcode relative to the captured image. This further promotes identification of the barcode control bar in the subsequent frame. Changes in size of the tracked barcode also indicate the distance between the handheld and the paper artifact. When moving away from the paper and a threshold distance has been reached, the recognition algorithm will automatically identify the barcode in the higher level that the tracked barcode is a part of (if the calculated position of the enclosing barcode is not entirely within the camera image then a suitable adjacent barcode is tracked). When moving the cameraphone toward the poster, the algorithm will move to the center barcode in the smaller dimension that is part of the tracked barcode, when that barcode exceeds a threshold size relative to the camera image. Because the size, orientation, and identity of higher-level barcodes can be determined by a tracked lower-level barcode (and vice versa), maintaining a fix as the distance from the paper increases or decreases is straightforward.

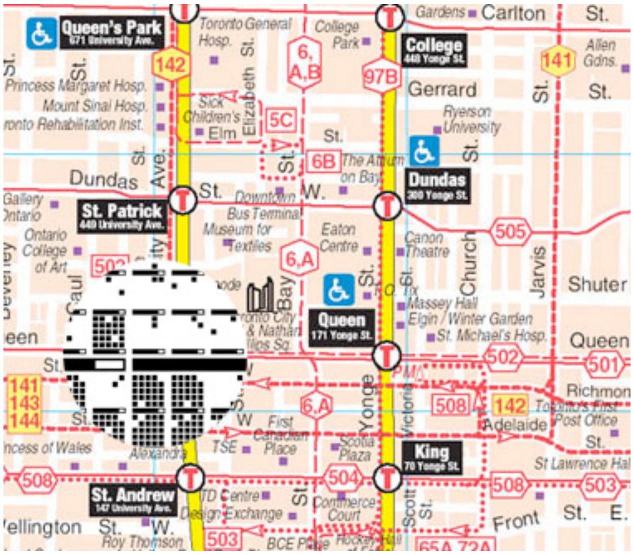

Figure 3. An illustration of how the barcode pattern would be used. Reflective only in the near-IR range, the pattern itself would be invisible to the naked eye. It would be printed alongside inks that are not reflective in the near-IR but which present the poster's visible content.

4. BARCODE RECOGNITION

A number of image recognition techniques are already used to read 2D barcodes. For example, in the QR-code standard, corners are marked and estimated so that the inside of code can be scanned [4, 5, 9]. Here we use our shape-based recognition algorithm for 2D barcode identification. The algorithm is a quick and efficient method that has been successfully applied to real-time identification and tracking of other regular patterns such as license plates [12] and map symbols [13]. As mentioned previously, each barcode has a control bar identifying the barcode's dimensions, orientation and bit density. Once a control bar is recognized by its shape and height/width ratio, and the barcode's structure identified via the control bar's blank region, the luminance attribute inside the barcode bit regions will be evaluated. A pre-defined threshold is applied to discern the "black" and "white" luminance levels so that the average intensity can be converted to a binary barcode bit value for each region. By using thresholds, the same algorithm works at the lowest level and with higher-level barcodes (whose bits are comprised of sparse and dense lower-level barcodes). Since this method identifies the barcode control bar with shape recognition, it tolerates camera rotation and distance from the paper.

The barcode recognition process has 5 steps: (1) edge detection, (2) shape detection, (3) identification of barcode control bar, (4) identification of the barcode orientation, dimensions and bit density using the control bar, and (5) calculating the value of barcode. Edge information is extracted first from the raw image and grouped into edges with distinct perceptual edge features called Generic Segments (GS') by the edge tracker discussed in [14]. Each GS is a perceptually distinguishable edge segment falling into one of 8 categories (Figure 1). In this case, only the first 4 types of GS need be identified in our 2D barcode pattern, for the common shape of control bars and bits is the rectangle.

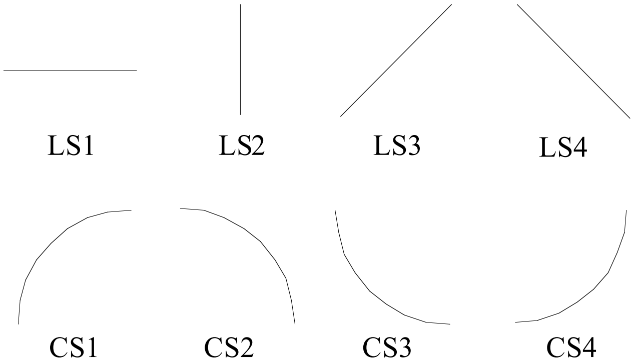

Figure 4. Generic Segments (GS) are the basis for shape descriptions (perceptual groupings)

The GS' carrying perceptual features are the main characteristics for shape detection and barcode identification. In the next step, these segments are perceptually grouped into region shapes represented by GS-based closures [15].

In order to be classified as a barcode control bar, each GS based shape is compared against the bar code control bar model. This target model is a common model for all control bars, which is pre-defined by a set of common recognition rules for control bar shape representation. If the control bar shape changes in the future, this system may be adapted by updating a subset or all of the recognition rules. To make the rectangular control bar model more robust to rotation and distance, the recognition rules are defined as follows:

1. at least 4 GSs in the shape including
    a) 2 pairs of parallels
    b) the two pairs of parallels are perpendicular to each other
2. the shape size must fall within a reasonable range to make sure that the identified barcode is clear in the image.
3. the ratio of shape width to height must fall within a specific range close to the pre-set width/height ratio of control bars.
4. The shape must embed a smaller white rectangle, used to determine barcode orientation, dimensions and bit density.

The shape that satisfies the recognition rules will be identified as a barcode control bar. Given this, its relative position in the image must be within a specified range to ensure that the barcode is completely captured in the image, prior to reading the barcode value. The barcode value is then determined by converting the average luminance value inside each bit region into a binary digit.

A main disadvantage of the shape recognition algorithm is that control bars may not be recognized due to image quality. Image quality can be impacted by low lighting conditions, high ambient reflectivity, shadow, fast camera movements, focus adjustments, and positioning the camera too far or too close to the paper.

5. CONCLUSION

We have described a recursive barcode pattern and supporting algorithms intended to permit interaction with paper artifacts using handheld devices equipped with cameras sensitive to wavelengths in the near-infrared range. The simplicity, regularity, and recursive organization of the pattern combine to promote fluid, real-time interaction at varying distances from the paper. Refinements to the algorithm are ongoing as it is currently being tested against a large grid printed in black ink. Future work will focus on printing in the near-IR range and addressing issues corresponding to this. Finally, two demonstration implementations are planned: one a portable map, the other a larger, stationary poster.

6. ACKNOWLEDGMENTS

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