

2008

# Development Of A Novel Finder Pattern For Effective Color 2D-Barcode Detection

Hiroko Kato  
*Edith Cowan University*

Keng T. Tan  
*Edith Cowan University*

Douglas Chai  
*Edith Cowan University*

## Development of a novel finder pattern for effective color 2D-barcode detection

Hiroko Kato  
Edith Cowan University  
School of Computer and  
Information Science  
2 Bradford Street Mount Lawley,  
WA 6050 AUSTRALIA  
hkato@student.ecu.edu.au

Keng T Tan  
School of Computer and  
Information Science  
2 Bradford Street Mount Lawley,  
WA 6050 AUSTRALIA  
a.tan@ecu.edu.au

Douglas Chai  
School of Engineering  
270 Joondalup Drive, Joondalup,  
WA 6027 AUSTRALIA  
d.chai@ecu.edu.au

### Abstract

*With a camera mobile phone, which has become a “must-have” device, 2D-barcode works as an interface to bridge the physical and digital world. As the notion of ubiquitous computing has permeated, developing a new 2D-barcode and its applications has been a growing trend worldwide. A 2D-barcode symbol consists of two broad areas: data area and guide area. The components of the latter is collectively called “finder pattern” and used in locating the 2D-barcode symbol. The failure of finding the target symbol prevents a barcode reader from successfully decoding the barcode. Hence, designing a functional finder pattern is one of the key for improving the robustness of barcode reading, and thus, the entire 2D-barcode system. We have designed a novel finder pattern integrated with a color 2D-barcode for camera mobile phone applications. Through the development and evaluation of the finder pattern for effective color 2D-barcode detection, this paper discusses keys to improve the functionality and reliability of finder patterns, which should be kept in mind when designing a finder pattern for any 2D-barcode symbol.*

### 1. Introduction

As the notion of ubiquitous computing permeates, the technologies and applications that aim to connect the physical and digital world have been developed in order to create an ubiquitous computing environment. Examples of such

technologies are barcode, Radio Frequency Identification (RFID), Near Field Communication (NFC) and so forth. They are used as either a visual or an invisible tag to connect these two worlds. Of these technologies, barcode technologies, especially two dimensional (2D) barcode have attracted the attention of many researchers due to its inexpensive operation, which resulted in the inventions of novel 2D-barcode symbologies.

Studies such as [6] and [7] proposed novel applications where 2D-barcode technology, together with wireless communication devices such as camera mobile phone, is used as interface to bridge the physical and digital world, and demonstrated the feasibility of their novel systems. From these studies, companies launched projects to develop systems that provide users with convenient and flexible services based on the Web link established via 2D-barcodes and mobile devices such as camera mobile phones and personal digital assistants (PDAs). The mobile devices perform the image processing task while providing continuous Internet connectivity. As a result, a variety of 2D-barcode symbologies have been developed and the trend is still progressing.

A 2D-barcode symbol can be roughly divided into 2 main areas: data area and guide area. The latter consists of components of the finder pattern (also known as position detection pattern) whereas the former is made up of the encoded data, error correcting data and/or barcode format information. A finder pattern is used to detect and locate a barcode symbol among other objects within an image captured by the image processing device. It is, in fact, one of

the key for successful reading of barcode symbols as the reading software cannot perform its subsequent tasks without first locating the barcode symbol.

Hence, our aim was to design a novel finder pattern that can be robustly detected by inexpensive cameras with limited capability such as built-in cameras of mobile phones. Through the development of a novel finder pattern integrated with a color 2D-barcode, we have examined the properties of finder patterns, their functions and their corresponding tasks. We also investigated the advantageous and disadvantageous features of particular finder patterns and their suitability for certain applications. When developing and evaluating the recognition algorithm of our finder pattern, the limitation of built-in camera of mobile phones was also addressed.

## 2. Finder pattern

The primary function of finder pattern is to be robustly detected. The robustness varies depending on the applications or under which environment a barcode symbol needs to operate. For example, if a 2D-barcode symbol is used to detect a moving target such as luggages on the conveyor belt, a bigger and more distinctive finder pattern should be required to be robustly detected and tracked. On the other hand, a smaller and less distinctive finder pattern may be sufficient for 2D-barcode whose position is known or can be easily assumed. That is, the application where a 2D-barcode is used is an important determinant of the properties of its finder pattern.

### 2.1. Properties of finder pattern

A finder pattern is usually made up of a solid border or a combination of borders and square dots in different sizes. A central circular finder pattern is also used by some 2D-barcodes. In order to be detected by the reading software, the components of a finder pattern must be distinguishable and measurable. Once, all the components of a finder pattern are located and properly measured, their geometric properties can be very informative, which are then used to estimate the properties of the entire symbol such as symbol size and orientation. The geometric properties of a finder pattern include its size, shape, the direction of a particular component or a combination of components.

### 2.2. Common tasks of finder pattern

Unlike human eyes, scanning devices or decoding software cannot distinguish a candidate 2D-barcode symbol from the background. Hence, the main task of a finder pattern is to tell the scanning and decoding device where the candidate symbol is, which is then followed by providing

information about itself so that the correction of orientation, distortion and tilt of the captured image can take place. Based on the information acquired from the components of the finder pattern, the relative size of the target 2D-barcode is estimated by the decoding software, enabling the accurate reading of the target barcode symbol.

Generally, 2D-barcode scanning and decoding process involves the following tasks:

- i. Detecting and locating the candidate barcode symbol;

This can be achieved by applying certain criteria to the found regions. The criteria are developed based on the known properties (e.g. size, shape, angle) of each component of the finder pattern.

- ii. Evaluating the validity of the candidate regions and filtering out those that do not satisfy the criteria;

- iii. Correcting the orientation, distortion and tilt of the located 2D-barcode symbol;

The position information of the components of the finder pattern is used for such corrections. The projective transformation that corrects symbol distortion of a finder pattern can be performed once the positions of four corresponding points are obtained [3].

- iv. Estimating the size of the barcode symbol;

It enables the accurate computation of the size of cells and the acquisition of the precise reading points on the 2D-barcode symbol; and

- v. Computing the number of cells of the target symbol.

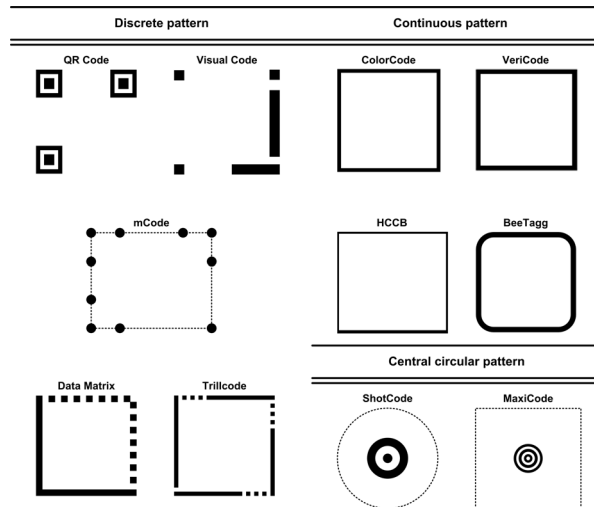
The number of cells can be obtained by estimating symbol size and cell size. The cell size can be obtained from the known properties of finder pattern (e.g. size and shape of the components).

For the detection and location of the target 2D-barcode symbol, the known geometric properties of a finder pattern such as its size and shape are basically used, whereas the positions of the components of the finder pattern are used in correcting the symbol's orientation, distortion and tilt. Hence, designing a finder pattern that works best for the purpose of a particular 2D-barcode system is important for robust barcode reading.

### 2.3. Finder pattern variations

A variety of finder patterns have been designed and we categorized them into three broad groups: discrete, continuous and central circular patterns. Figure 1 presents examples of these finder patterns.

The best finder pattern for a particular 2D-barcode depends on the purpose of its use or applications, the tasks



**Figure 1. Finder pattern examples**

of the finder pattern, design criteria of the symbol and so forth. For example, MaxiCode and ShotCode (also known as SpotCode, which is a derivative of the TRIP code) have adopted the central “bull’s eye” as their finder pattern. The initial purpose of both 2D-barcodes was to handle moving targets. The main task of the MaxiCode is to locate and decode the target symbols placed on the surface of numerous luggages on a conveyor belt, which requires the ultra-fast reading of the target barcode symbols. The TRIP code was developed to locate and track moving targets such as human so that the TRIP system can provide a context-aware environment vis-a-vis the world of ubiquitous computing. The circular shape works best to meet such a requirement.

According to Diego López de Ipiña and Paulo R. S. Mendonça and Andy Hopper [1], circles are less common shapes than right angles, squares and rectangles in man-made cluttered environments, thus, the central “bull’s eye” of a TRIP code represents a very distinctive pattern. The salient features of circle and ellipse, the projection of circle in an image, enable the robust and rapid detection of the target barcode symbol. Moreover, it can be represented in a compact and elegant form by a symmetric (3×3) matrix. In contrast, the detection of squares causes an expensive computational task since there may be many straight lines and edges within the image.

On the other hand, mCode uses unobtrusive finder pattern that is made up of the combination of dot-like cells or blobs. Such finder pattern is not only space-effective but also suitable for advertising applications, allowing mCode to be integrated within commercial or artistic images such as a company logo without spoiling its appearance as a whole. mCode was invented with the aim of developing a database 2D-barcode suitable for such advertisement.

Hence, the blob finder pattern is ideal for mCode.

The aim of the QR Code development was to provide database 2D-barcode that can perform ultra-fast reading, handling not only stationary objects but also moving targets on a conveyor belt for industrial usage. The database 2D-barcode refers to any 2D-barcode symbology that is flexible in data capacity and can operate as robust and portable data files, as compared to those that work only as an index to a backend database (i.e. index 2D-barcode) [5]. The resultant finder pattern is distinctive squares at the 3 corners of the symbol with each composed of 3 different-sized black and white squares. The unique ratio of the black and white on a line passing the centre of the finder pattern in any angle (i.e. 1:1:3:1:1) enables the symbol to be detected quickly.

### 3. Development of a novel finder pattern

When designing the finder pattern for a 2D-barcode symbol, the first step is to determine the applications of the barcode. As discussed previously, different features and capabilities are required in a finder pattern, depending on the applications where the 2D-barcode is used. In our prototype development, the following barcode features were required. Our 2D-barcode is:

- i. a color 2D-barcode that requires color reference cells within the symbol;
- ii. a database 2D-barcode whose data capacity can be flexibly changed;
- iii. to be used as a visual tag presented on media such as paper or computer display;
- iv. to be used for applications where a built-in camera of mobile phone captures the image for on-phone processing; and
- v. maximized for data capacity within a given symbol space.

In order to decode colored symbols robustly, the use of reference color cells was considered [2]. Different image-capturing, image-processing and printing devices, as well as paper quality can affect the reconstruction of a color image. Lighting conditions can also affect the color value of a captured image. The use of reference color can improve the robust reading of color symbols by providing the standard color for correctly distinguishing each reproduced cell. The value of each cell color in the data area is determined relative to the value of the standard color in the reference cells. Since the relative difference between the cell color and the standard color is consistent, a reader can correctly retrieve the original data.

However, including color reference area within the data area of a 2D-barcode symbol reduces the space for encoding data. It conflicts with our other goal of maximizing the data capacity within a given space. Hence, we have designed a finder pattern that includes the color reference cells within itself. Checker borders were also integrated into the finder pattern to provide information such as the number of cells both vertically and horizontally. The checker borders can also work as a timing pattern.

### 3.1. Structure of the finder pattern

The structure of our proposed finder pattern is presented in Figure 2.

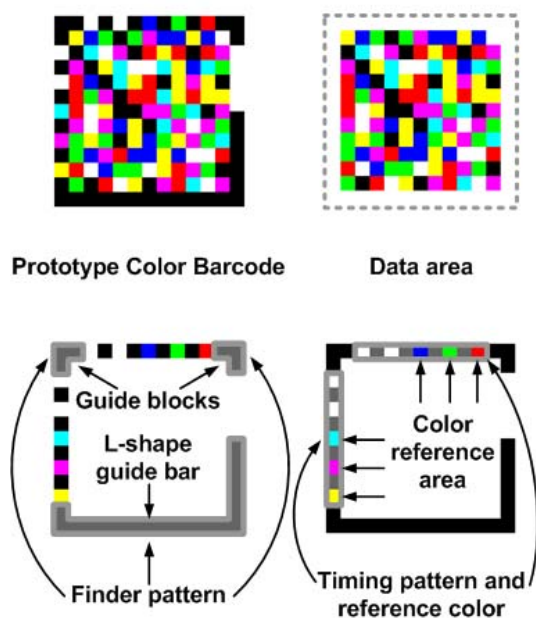


Figure 2. Structure of example color 2D-barcode with the prototype finder pattern

The finder pattern is made up of two major components: guide area and reference area. The former consists of two guide blocks and a L-shape guide bar, while the latter is composed of two checker borders in which the color reference cells are integrated.

The L-shape guide bar is first used in detecting the location of a target barcode symbol, and then, for correcting the symbol orientation. The first task of the guide blocks are verifying the validity of the located region as a candidate for the L-shape guide bar. The next task is, together with the L-shape guide bar, to detect and correct the symbol distortion and tilt. The properties of L-shaped guide bar, namely, its

unique shape and its large size, enables robust detection and location of the target barcode symbol.

In Figure 2, eight different colors are used to encode the data in the color 2D-barcode: red, green, blue, cyan, magenta, yellow, black and white. Their reference color cells are integrated in the known positions between the checker border cells so that they can provide color reference values for later use in decoding the 2D-barcode. Since the black and white colors are used to compose the checker borders, the reference values of black and white colors can also be retrieved from these checkered border cells.

### 3.2. Recognition algorithm of the finder pattern

Our prototype 2D-barcode is designed for use with mobile devices, especially, camera mobile phones. Hence, the recognition algorithm is developed for the images captured by camera mobile phones. Once, the image is captured, the location of the finder pattern is achieved via the following steps:

**Thresholding and binarizing the captured image (1).** Thresholding is performed to convert the re-constructed colored image to a binarized image or black and white image, which facilitates detection and correction of the target barcode symbol. This process removes the effect of color including the colors in the reference cells, leaving the black and white checker borders. Thresholding was conducted in two different ways: using the modified adaptive thresholding method [7] originally developed by [8] and using the thresholding value obtained by the experiments.

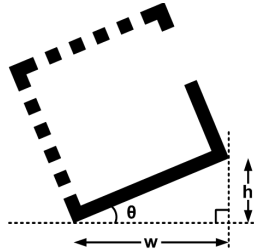
The adaptive thresholding is an effective method to remove the light effect from the input image. Since our prototype 2D-barcode encodes data into color cells, the adaptive thresholding method was applied to the three color channels or R, G, B separately, resulting in the three binarized images. They were then combined together and binarized as a whole.

**Finding the maximum region within the input image as a candidate for the L-shape guide bar (2).** The ratio of the longest bar to the second longest of the L-shaped guide bar is fixed at 2:1. The size of the smallest bar of the L-shape guide bar is equivalent to the size of 2 data cells. Once, the maximum region is found, the coordinates of its four corners are calculated, which are used to measure the size of the bars. The size of each bar and the coordinates of the four corners enable the calculation of the orientation of the L-shape guide bar.

**Correcting the orientation of the candidate symbol via the L-shape guide bar (3).** The tangent of an angle is the ratio of the length of the opposite side to the length of the adjacent side. The lengths of the opposite side ( $h$ ) and the adjacent side ( $w$ ) can be obtained via the coordinates of

the both ends of the longest bar (see, Figure 3). Hence, the orientation angle ( $\theta$ ) between the x-axis of the image and the base of the longest bar can be calculated as

$$\theta = \arctan \frac{h}{w}$$



**Figure 3. 2D-barcode symbol orientation**

**Searching for the 2 guide blocks (4).** After the orientation of the entire image is corrected, the area for searching each guide block becomes narrower. Furthermore, the positions of the 2 guide blocks relative to that of the L-shape guide bar can be estimated although accurate estimation may not be always possible due to symbol distortion. The properties of the guide block such as its size and shape (i.e. small L-shape) are used as criteria to determine whether or not the located region is the designated guide block. Each guide block is equivalent to the size of 3 cells. Failure to locate any regions that satisfy the criteria within the search area indicates that the candidate L-shape guide bar was a false positive. As a result, the reading software searches for the second maximum region as another candidate for the L-shape guide bar. The process from (2) to (4) repeats until all components of the finder pattern are successfully located.

**Performing projective mapping to correct symbol distortion (5).** The projective mapping (also known as perspective transformation [3]) is quadrilaterals to quadrilaterals mapping. It can be performed once four corresponding points are located. The center of cells at the four corners of the finder pattern are used for the calculation.

Once, all the components of the finder pattern are located and the required corrections are performed, the next step is to decode the 2D-barcode.

### 3.3. Decoding algorithm

In order to maximize data capacity within a given space, the data area of our prototype 2D-barcode does not include the format information such as the number of cells. Thus, a priori to the 2D-barcode reading, the number of cells must be computed. The decoding process of our prototype 2D-barcode takes the following steps:

**Calculating the number of cells (1).** The size of black and white cells of the checker borders or timing pattern corresponds to the size of data cells. Hence, the cell size is calculated by measuring black and white cells of the both vertical and horizontal checker borders. The number of cells is computed once the size of cells is acquired. It should be noted that the color reference cells are read as “white” since the binarized image is used for all the computation. The timing patterns are also used to calculate the centroid of each cell and modify it when symbol distortion and/or changes in cell pitch are detected.

**Retrieving the color values of the color reference cells (2).** For this step, the operation is applied to the color image. First of all, the values of each color is retrieved from the corresponding color reference cell.

**Reading the value of the center of each cell in the data area (3).** Based on the values of the color reference cells obtained in (2), the color of the data cells is detected.

This step is followed by decoding the 2D-barcode and retrieving the encoded data. However, this is out of the scope of this paper.

## 4. Evaluation of the novel finder pattern

In order to verify the effectiveness and robustness of our finder pattern, its recognition and decoding algorithms, we conducted the following experiments.

### 4.1. Evaluation methods

The novel finder pattern is designed for use with camera mobile phones. To evaluate the robustness of the finder pattern recognition algorithm, two camera mobile phones (i.e. a Nokia 6600 with a VGA camera and a Sanyo W33SA II with a 1.3-megapixel camera) are used to capture the subject finder pattern integrated with a color 2D-barcode symbols printed on paper. The camera resolution of the Sanyo W33SA II was set to Quarter Video Graphic Array (QVGA) (i.e.  $320 \times 240$  pixels) or VGA (i.e.  $640 \times 480$  pixels) to distinguish the effect of different camera resolutions.

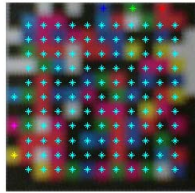
We designed a finder pattern for the database 2D-barcode that is flexible in data capacity. Thus, in our experiments, we used barcode symbols with different data capacities:  $9 \times 9$ ,  $11 \times 11$ ,  $21 \times 21$  and  $31 \times 31$  data cells, in the symbol size of  $2 \times 2$ ,  $2 \times 2$ ,  $3 \times 3$  and  $4 \times 4$  cm<sup>2</sup>, respectively. We set the minimum data capacity of our prototype 2D-barcode to  $9 \times 9$  cells. Forty samples are created to conduct the experiments for the  $9 \times 9$  symbol, prior to the experiments for symbols with greater data capacity. Then, twenty samples were tested for each  $11 \times 11$ ,  $21 \times 21$  and  $31 \times 31$  variations. Half of the samples are captured by the Nokia 6600 and another half by the Sanyo W33SA II for all the symbols tested.

The room used for the experiments was lit by ambient daylight and no additional lighting was used. The sample symbols are captured to cover a wide spectrum of potential image appearances, including samples with varying orientations, with different distortions, with different backgrounds, under the effect of shadow and samples near other written characters. The samples in the shadow were created in a room lit by an incandescent light.

## 4.2. Evaluation metric

The evaluation is to examine the robustness of the recognition and decoding algorithms of our novel finder pattern. The recognition algorithm enables the accurate location of the finder pattern and its corrections as required. Once, the first step is correctly performed, the decoding algorithm calculates the number of cells of the 2D-barcode symbol, which allows the reading software to locate the accurate reference points of the color reference cells and the center of each cell in the data area.

We programed the reading software to mark the read points with cyan asterisks (i.e. \*). When all the reference points and the centers of the data cells are correctly marked, we regarded it as a successful read. Figure 4 presents an example sample image that is successfully read.



**Figure 4. Example of the successfully read sample image**

## 5. Results and observations

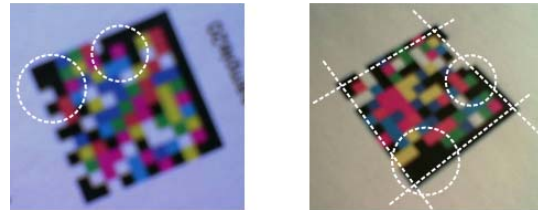
Prior to our experiments, we have conducted pre-experiments using  $9 \times 9$  symbols to fine-tune the reading software. Two important findings from this stage were:

- i. For the experiments, eight colors (i.e. red, green, blue, cyan, magenta, yellow, black and white) are encoded in the data area. When black cells are encoded adjacent to the component(s) of the finder pattern, it changes the properties of finder pattern (e.g. size and shape), which considerably affects the robustness of the finder pattern. The effect on the two guide blocks was more critical than that on the L-shape guide bar.

Possible solutions are 1) encoding color cells without using black cell (i.e. selecting an alternative color), 2) developing a scheme to avoid encoding black cells adjacent to the components of the finder pattern and 3) giving more leniency to the finder pattern selection criteria, allowing for this occurrence.

- ii. When the symbol distortion is considerably high, position estimation for the two guide blocks may be rather inaccurate despite successful correction of the barcode symbol orientation.

Figure 5 presents the examples of a clustered guide block and L-shape guide bars. The L-shape guide bar of the example on the left is also clustered. However, it had no negative effect on the subsequent orientation correction process. Although, the L-shape guide bar of the right example was heavily clustered, it also showed no negative effect. However, due to the combination of symbol distortion and rotation, the estimated positions of the 2 guide blocks were inaccurate.



**Figure 5. Examples of clustered guide block (left) and clustered L-shape guide bar (right)**

To solve these problems simultaneously, we decided to select the third solution, which is providing more leniency to the finder pattern selection criteria and enabling wider area of searching for the guide blocks. These changes enabled the successful location and correction in both of the above examples.

### 5.1. Experiment results

The experiment results indicated that our finder pattern and recognition algorithm can operate robustly. When the sample images are captured by the Sanyo W33SA II, it achieved 100% success in locating the color reference points and centers of all the cells in the data area. These images were captured using three different camera resolution settings. The images captured using QVGA setting was sufficiently clear to accurately retrieve the designated points. On the other hand, processing the images captured using 1.3 megapixels setting was rather slow.

In contrast, the images captured by the Nokia 6600 with a VGA camera was quite blur. Although 100% of the  $9 \times 9$  and  $11 \times 11$  symbols were successfully read, the percentage was reduced to  $\frac{2}{3}$ , when reading samples with greater data capacity.

The Sanyo W33SA II is equipped with an auto-focus function whereas the Nokia 6600 is not. It causes a significant difference in the sharpness of the reconstructed images. After the thresholding, the size of the two guide blocks was either considerably reduced or increased depending on the lighting effect. On the whole, the size of the guide blocks were reduced. However, the images captured under the effect of shadowing sometimes increased the size of its guide blocks since part of darkened cells adjacent to the guide blocks were recognized as black by the reading software and were mistaken as part of the guide blocks. In either case, it confused the recognition algorithm significantly.

When developing the recognition algorithm, we considered two thresholding schemes: the modified adaptive thresholding method [7] originally developed by [8] and the method that use thresholding values obtained by experiments. The former scheme demonstrated its strong capability in removing the lighting effect. However, it is often that the resultant image introduced more noise than the alternative scheme. In fact, the latter often produced clearer outcomes in our observations. Furthermore, it can save considerable computational power.

The novel feature of our finder pattern, namely, integration of the reference color cells within the finder pattern itself, seemed rather promising. Successful location of the finder pattern enables the retrieval of reference color values.

## 5.2. Key findings

Three key findings that may help improve the robustness of finder patterns are:

- i. It is very important to develop an effective thresholding or binarizing method.

This is especially important when designing a finder pattern integrated with a database 2D-barcode whose data capacity is not fixed. Generally, the size of cells is decreased when data capacity is increased since there is often limited space for reproducing a 2D-barcode symbol. Inaccurate calculation by a few pixels may result in a failure of the entire symbol decoding process. Developing a very reliable thresholding method is a must, especially when using image capturing devices without a focusing function.

- ii. Distortion is one of the major causes for decoding failure. One solution is to develop an interactive reading software rather than the normal “capture first, decode later” approach.

Generally users attempt to adjust their camera mobile phones to successfully read the 2D-barcode symbols if prompts are given interactively. This allows the reading software to capture an image in its best state and avoid reading heavily distorted images.

- iii. A continuous finder pattern with reasonable width may be a better choice for database 2D-barcodes.

In our experiments, the key for a successful read was to correctly locate the two guide blocks, especially when data capacity was increased. The criterion to select a candidate L-shape guide bar was based on its area, which never returned a false positive/negative throughout our experiments. Including all the components into one wide frame may also reduce the chance of losing any components of finder pattern completely. This may allow the reading software to work properly even when the finder pattern is partially damaged.

## 6. Conclusion

One must keep in mind that the possibility for successful 2D-barcode reading dramatically drops when the finder pattern get damaged. With error correcting scheme such as Reed-Solomon code, damaged data area can be corrected. However, the finder pattern cannot be restored once it is damaged [4], often resulting in poor reading performance, or worse, a failure in reading the symbol. Hence, it is important to design a finder pattern that is robust enough to perform its tasks even when it is partially damaged.

Square finder patterns with either solid border (e.g. ones used in the ColorCode and VeriCode symbols) or a combination of solid and broken borders (e.g. ones used in the Data Matrix and Trillcode symbols) are most commonly used. When small dot-like components are used to compose a finder pattern, losing one of them, or even part of the dot may confuse the reading software significantly. When increasing the data density of a 2D-barcode for a given space, the size of finder pattern decreases as the size of each cell decreases. Very small finder pattern may be missed by a reader even when it is not damaged. A background object that has similar visual properties may be wrongly selected as a candidate component for the designated finder pattern.

Designing a finder pattern similar to the one used in the QR Code symbol is a possible solution. The large components of the finder pattern can provide considerable robustness regardless of the barcode symbol size. However, increasing the size of a finder pattern would decrease the space available for encoding data, resulting in less data capacity for a given symbol size. To ensure the robustness and reliability of 2D-barcode reading while improving data capacity, it may be prudent to design a solid continuous finder



pattern unless this conflicts with the purposive use of particular 2D-barcode.

The novel feature of our finder pattern is its integration with additional information such as color reference cells. Finder pattern is the first object to be located by the reading software, thus, its successful location can ensure the robustness of reading the color 2D-barcode.

**References**

[1] D. L. de Ipiña, P. R. S. Mendonça, and A. Hopper. Trip: A low-cost vision-based location system for ubiquitous computing. *Personal Ubiquitous Comput.*, 6(3):206–219, 2002.

[2] T. Han, C. Cheong, N. Lee, and E. Shin. Machine readable code image and method of encoding and decoding the same, 2006.

[3] P. S. Heckbert. Fundamentals of texture mapping and image warping. Technical report, Berkeley, CA, USA, 1989.

[4] . Japan Automatic Identification Systems Association. . . . .  
 . . . . .  
 • *Understanding 2D symbologies: Detailed Information On Barcodes*. Tokyo: Ohmsha, 2004.

[5] H. Kato and K. T. Tan. Pervasive 2d barcodes for camera phone applications. *IEEE Pervasive Computing*, 6(4):76–85, 2007.

[6] A. Madhavapeddy, D. Scott, R. Sharp, and E. Upton. Using camara-phone to enhance human-computer interaction. In *UbiComp 2004 The sixth International Conference on Ubiquitous Computing*, Sept. 2004.

[7] M. Rohs. Real-world interaction with camera-phones. In *2nd International symposium on Ubiquitous Computing Sysrwma (UCS 2004)*. Tokyo, Japan, Nov. 2004.

[8] P. D. Wellner. Adaptive thresholding for the digitaldesk: Technical report epc-93-110. Technical report, Rank Xerox Research Centre, Cambridge, UK, 1993.