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2D-barcode for mobile devices

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USE OF THESIS

2D-barcode for Mobile Devices

by

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Abstract

2D-barcodes were designed to carry significantly more data than its 1D counterpart. These codes are often used in industrial information tagging applications where high data capacity, mobility, and data robustness are required. Wireless mobile devices such as camera phones and Portable Digital Assistants (PDAs) have evolved from just a mobile voice communication device to what is now a mobile multimedia computing platform.

Recent integration of these two mobile technologies has sparked some interesting applications where 2D-barcodes work as visual tags and/or information source and camera phones performs image processing tasks on the device itself. One of such applications is hyperlink establishment. The 2D symbol captured by a camera phone is decoded by the software installed in the phone. Then the web site indicated by the data encoded in a symbol is automatically accessed and shown in the display of the camera phone. Nonetheless, this new mobile applications area is still at its infancy. Each proposed mobile 2D-barcode application has its own choice of code, but no standard exists nor is there any study done on what are the criteria for setting a standard 2D-barcode for mobile phones.

This study intends to address this void. The first phase of the study is qualitative examination. In order to select a best standard 2D-barcode, firstly, features desirable for a standard 2D-barcode that is optimized for the mobile phone platform are identified. The second step is to establish the criteria based on the features identified. These

features are based on the operating limitations and attributes of camera phones in general use today. All published and accessible 2D-barcodes are thoroughly examined in terms of criteria set for the selection of a best 2D-barcode for camera phone applications.

In the second phase, the 2D-barcodes that have higher potential to be chosen as a standard code are experimentally examined against the three criteria: light condition, distance, whether or not a 2D-barcode supports VGA resolution. Each sample 2D-barcode is captured by a camera phone with VGA resolution and the outcome is tested using an image analysis tool written in the scientific language called MATLAB.

The outcome of this study is the selection of the most suitable 2D-barcode for applications where mobile devices such as camera phones are utilized.

Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material

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Student Number: 2015893

November 2005

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1 Introduction

First of all, it is important to know the relationship between Code and Symbol:

> The shorthand used to represent the verbal description of an item is called the product identification code. The product identification code is shortened to the word "code." The use of the word "code" should not be confused with the bar code, which is technically called the symbol. A barcode symbol is used to identify people and places as well as product (Bushnell & Meyers, 1999, p.44).

1.1 Motivation

Barcode technology is one of the automatic identification, keyless data entry methods. It has been more than decades since the technology was globally accepted and came into common use. The barcode itself is a group of data stored in the shape of black and white rectangles, and it is usually attached on a product to carry specific information. It can be read easily, quickly, and precisely by a scanner. The barcode technology has rapidly become popular throughout the world because of its accuracy, user-friendliness and cost-effective operation.

The traditional barcode, however, has a major disadvantage in its data capacity. As a solution to remedy the shortcomings of traditional barcodes, two dimensional (2D) barcode technology was introduced and has been developed. At present, more than thirty 2D-barcodes exists. The greater data capacity allows each 2D-barcode to add its original features such as error correction, security, and multi-language encoding capability. These advantageous features have made 2D-barcode more attractive and many industries and organizations have utilized these codes in their tagging applications.

The number of mobile phones that are equipped with digital cameras has increased in the last few years. The camera function of a mobile phone enables it to interact with physical objects including 2D-barcodes. This opens a possibility for new applications based on the integration of 2D-barcode technology and camera phones. Such application is feasible not only technologically but also economically as the printed tags (i.e. barcode) is the least expensive and versatile tagging technology. In addition, there is a trend that the computers have become smaller, cheaper, and more abundant including mobile multimedia computing platform such as camera phone.

The traditional barcode/symbol (i.e. 1D-barcode) selection was conducted taking iinto account that all the interest groups (e.g. grocery retailers, wholesalers, and manufacturers) use the same symbol structure. Another requirement was that each code can be uniquely identified. It is based on the notion that the barcode system works in the efficient and effective way only when all the interest groups use the codes that have the same structure. This led to the globally successful implementation of 1D-barcode systems.

In contrast, the new mobile application area where 2D-barcode is utilized is still at its infancy. One of the possible reasons for this is the lack of a standard 2D-barcode. Each proposed mobile application uses its own choice of code and no standard exists nor is there any study undertaken to set the criteria for selecting a best 2D-barcode for standardization.

This thesis identifies the most suitable 2D-barcode as standard for camera phone applications among all the existing 2D-barcodes by firstly setting the criteria for the selection, then examining each 2D-barcode against the criteria established.

1.2 Approach

This study is to select a best 2D-barcode for camera phone applications. This will be achieved through the following:

i. The establishment of criteria to select a best 2D-barcode for camera phone applications considering the operating limitations and attributes of camera-equipped mobile phones presently in general use.

ii. The qualitative examination of all the existing 2D-barcodes against the criteria established

iii. The conduct of the experiments to quantitatively examine the sample 2D-barcodes against three criteria: light condition, distance, and whether or not a 2D-barcode support VGA camera resolution.

1.3 Organization

Chapter 2 establishes the context for this thesis by describing barcode technology in general. Chapter 3 analyse the structure and the features of 2D-barcodes that have been utilized for camera phone applications. Chapter 4 introduces the development of 2D-barcodes, their capabilities, and relevant applications and describe the recent trend in 2D-barcode applications. Chapter 5 reports on the two assessments for the standardization. Chapter 6 considers the contribution of this thesis and the possible work in this area that can be conducted in the future.

2 Barcode Technology

2.1 Introduction

2.1.1 Development of Barcode Technology

The idea of keyless data entry/automatic identification system has a relatively long history. According to LaMoreaux (1995), its origine ascends back to the early 1800s, when devices were patented as reading aids for the blind. There are different types of keyless data entry/automatic identification systems such as Optical Character Recognition (OCR) system, Radio Frequency Identification (RFID) systems, magnetic stripe technology as well as barcode technology (see Appendix 1, p.159). Each one of them has its advantages and disadvantages.

One of the most distinctive advantages of the barcode use is its inexpensive operation. LaMoreaux (1995) claims that printing the information in machine readable form is the least expensive methods. Rekimoto and Ayatsuka (2000) support this idea stating that "Printed tags are probably the least expensive and most versatile tagging technology: They can be easily made by normal printers, can be attached to almost any physical object, and can be recognized by mobile readers". Another advantage of use of barcode, which is merely lines and spaces, is that it is the simplest method to read information into a computer without human keystrokes (LaMoreaux, p.3, 1995).

Advanced technology, especially the emergence of computers accelerated the search for better methods of data entry and as a result, data recognition patterns similar to the barcode technology were developed in 1950s or earlier (LaMoreaux, 1995).

Despite the advance in computer design, however, there were few means to scan the patterns at the time. It was after the arrival of the moving-beam laser scanner in 1960s that the practical scanning of the patters became possible (LaMoreaux, 1995). This was followed by the invention of Charge Coupled Devices (CCD) scanner and similar pixel readers.

The demand for product coding in the USA escalated strongly in the end of 1960s and 1970s. The initial purpose for the use of the keyless data entry and automatic identification system was to minimize errors caused by human mistakes during data entry and to process data efficiently. That is, barcode technology was to be used to improve the accuracy and speed of computer data entry. This solution was in response to the needs of retailers, wholesalers and grocery manufacturers at the time, which played a vital role towards the adoption and standardization of barcodes in the USA. The use of barcode also enables retail stores to register data on each product at the point of sale (POS) and obtain real-time information on products, which in turn allows them to monitor and control products timely.

Some experiments and trials conducted by supermarkets and retailers such as Kroger store in Cincinnati in the USA and Migros and Zellweger in Switzerland in 1972 proved the promising outcomes of barcode use (Tokura, 2002). The former used a code known as "Bull's eye" and a code similar to the Bull's eye (but only upper half of it) is used in the latter's trial (Tokura, 2002). Figure 1 shows the symbol used in each trial.

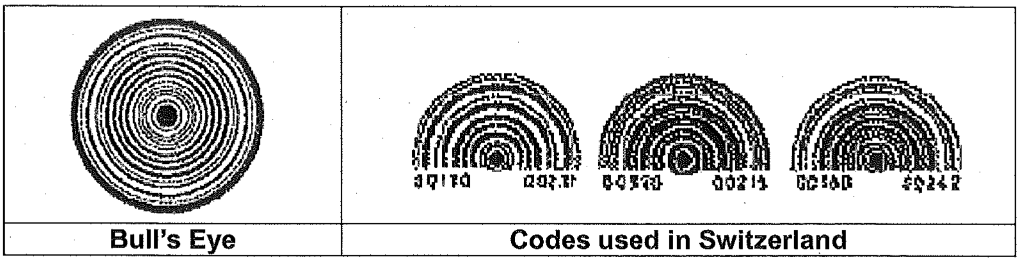


Figure 1: Codes used for the trials that test the effect of the barcode use at POS

Source: Tutorial for beginners: Barcode Tutorial for Beginners (Tokura, 2002). Retrieved September 11, 2005, from http://www. jaisa.or.jp/about/kisojirei.html

At April 3, 1973, the grocery industry formally established Universal Product Code (UPC) as the standard bar code symbology for product marking and it is considered to be the birth of the one dimensional (1D) barcode (LaMoreaux, 1995), (Adams, 2004). The symbol set submitted by IBM with minor changes was selected as UPC among 8 candidates and is still in use in the USA today (Adams, 2004) (see, Figure 2).

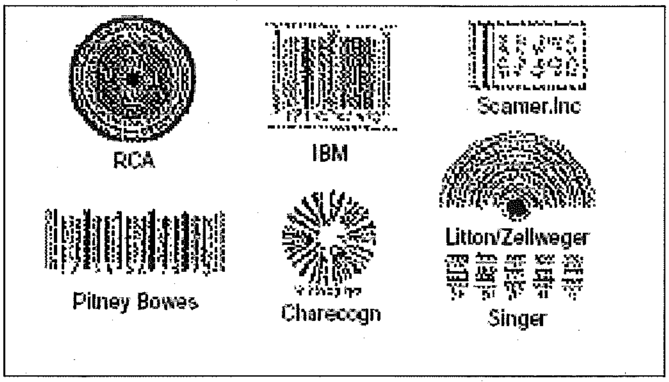


Figure 2: Examples of proposed codes as UPC

Source: Tutorial for beginners: Barcode Tutorial for Beginners(Tokura, 2002). Retrieved September 11, 2005, from http://www.jaisa.or.jp/about/kisojirei.html

The UPC was the first linear bar code symbology widely adopted (Adams, 2004). The name UPC indicates, the whole activity for the code/symbol selection has been conducted taking it for granted that all the interest groups (e.g. grocery manufacturer, wholesaler, and retailer) use the same symbol structure. In addition, each code can be uniquely identified. It works in the efficient and effective way only when all groups involved use the codes that have the same structure. It led to the formation of the committee and its collaborative work in the USA. Foreign interest in UPC led to the adoption of the European Article Numbering (EAN) code format, similar to UPC, in December 1976 (Adams, 2004). Whereas UPC code format was established only considering the code use within the United States, the EAN format was adopted under the consideration of the use of the code in different countries. Hence an EAN code includes 2 or 3 country identification numbers. Not only European countries but other counties all over the world have adopted a code that has same structure as EAN code and the EAN format. It has been adopted in more than a hundred countries, and literally has become the global standard 1D-barcode. The use of a few globally standardized codes has brought enormous benefits to all the interest groups that include consumers as well as manufacturer, wholesalers, and retailers. It is the key factor of the proliferation of 1D-barcode at the moment and also in the future.

After a decade since the traditional barcode was officially introduced and the enormous success of the use of 1D-barcode, especially in distribution systems became obvious, the growing demand to encode more data than 1D-barcode can accommodate has escalated especially in industrial field; such as automotive industry and electronic industry. For example, Toyota Motor Corporation and Denso, a Japanese automotive supplier, collaboratively devised a kind of stacked barcode using a linear barcode called Codabar. The devised code consists of 5-row-Codabar, 11-row-Codabar, and again 5-row-Codabar and was utilized in a sign called Kanban that is used to enhance productivity in Toyota's "Just in Time" system. The study for the system that utilizes a sign (i.e. Kanban) containing 2D-barcode like symbologies started as early as 1973

(DENSO SI COROPORATION., 2003). At present, 2D-symbology-like barcode has been replaced with real 2D symbology. Figure 3 and 4 show early Kanban (i.e. sign) and recent Kanban, respectively.

Figure 3: Barcode "Kanban (Sign)"

Source: Understanding 2D Symbologies: Detailed Information on Barcodes (Japan Automatic Identification Systems Association, 2004), Tokyo: Ohms

Figure 4: Recent Barcode "Kanban (Sign)"

Source: New Work Item Proposal Micro QR Code. Inclusion to ISO/IEC 18004 QR Code (ISO/IEC SC 31 National Body of Japan, 2003). Retrieved October 13, 2005, from http://isotc.iso.org/livelink/livelink

Such demand led to the development of two dimensional (2D) barcodes that can encode 10 to 100 times more data than their 1D counterpart that are only capable of encoding up to approximately 20 alphanumeric characters. In addition, increased data capacity enables some 2D-barcodes to provide the Unicode standard in comparison with

1D-barcode that can only encode the complete ASCII128-character set at a maximum. This may contribute to the global growth in use of 2D-barcodes. In general, 2D-barcode is advantageous in applications where space is a problem, where a database cannot be accessed, or where high-speed sorting/processing is required (LaMoreaux, 1995). However, the ability to encode a portable database has made 2D-barcodes attractive in applications where space is not at a premium in recent years (Barnes, Bradshaw, Day, Schott, & Wilson, 1999) and more than thirty different 2D symbologies have been developed and utilized especially for industrial applications. The automotive industries are one of the pioneers that utilized different 2D-barcodes in a variety of ways according to the applications and/or the operating environments. This played an important role for its current proliferation.

Recently, there has been an increase in the number of mobile phones that are equipped with digital cameras (Thoresson, 2003). The camera function of a mobile phone enables it to interact with physical objects including two dimensional barcode (Rohs, 2004). This opens a possibility for new applications based on the combination of 2D-barcode technology and camera enabled mobile phones.

In addition to 1D and 2D-barcode, 3 dimensional (3D) barcode also exists. 3D-barcode known as Bumpy Barcode is any linear barcode that is embossed on the surface of the materials (Adams, 2004). Such barcode can be used where printed labels will not adhere, or will be otherwise destroyed by a hostile or abrasive environment (Adams, 2004).

2.1.2 Future of Barcode Technology

It has been about thirty-five years since the first barcode system was first introduced in a supermarket in Cincinnati in the USA (AINIX Corporation., 2002). Barcode technology has evolved together with the development of printing technique. The printed tags are inexpensively produced and there never have had a dramatic increase in the cost of papers and printing devices. In addition, the information encoded into the form of barcodes including both 1D and 2D symbols, can be used and/or stored without risks for a long period of time.

With the integration of CCD cameras, in recent years, mobile phones have become a networked personal image capture devices (Rohs, 2004). Integration of such mobile phones, also called camera phones with 2D-barcode technology allows the 2D symbols to be used for the general use. Programmable camera phones, for instance, can perform image processing tasks on the phone itself and use the outcome as an additional means of input by the user and a source of context data (Rohs, 2004). An example of the former is the exchange of the business cards. The physical hyperlink to the web page led by the information encoded into 2D-barcodes is one of the examples of the latter. Such applications are important in that it opened the door for ordinary users to use 2D-barcode technology. This is a new type of service enabled by the recent proliferation of camera equipped mobile phones and the growing popularity of 2D symbologies, and it has potential for further development. One of the most remarkable aspects of this new technology is that it uses a re-writable medium, namely the display screen of camera phones (AINIX Corporation., 2002). That is, symbols can be re-created and used over and over again with no additional cost.

Barcode technology has been often seen in comparison with another technology with growing popularity, namely RFID technology (Japan Automatic Identification Systems Association., 2004). IC cards, magnetic stripes as well as RFID have been used where there is a need for changes in information encoded. The problem of using such media is that they are not only costly but also invisible. Hence, the use of 2D-barcode is invaluable in both economically and technologically as it is inexpensive, visible, and now re-writable. At present, such applications in which the display screen is used as a re-writable medium are only limited to the use with mobile devices such as camera phones and Personal Digital Assistances (PDAs). However, it is possible to develop applications that use similar medium for industrial use. If that is the case, the demand for the barcode technology may progress even more rapidly.

Lately, direct marking technique of barcodes has also attracted attentions of interest groups such as the Air Transport Association (ATA), National Aeronautics and Space Association (NASA), and the Automotive Industry Action Group (AIAG) (Japan Automatic Identification Systems Association., 2004).

Considering the potential of 2D-barcodes and the rapid progress of technologies that can be integrated with barcode technology, it is possible to say that the overall future of barcode technology is still promising. The current use of barcode technology is provided in Table 23, in Appendix 2 (p. 160).

2.2 Barcode Systems

2.2.1 One Dimensional (1D) Barcode

In the past more than 10 1D-barcode was introduced (Japan Automatic Identification Systems Association., 2004). EAN code is the most widely used 1 dimensional barcode among them and is practically a standard barcode throughout the world. In addition, EAN is utilized as standard barcode in Australia (Australian Government Publishing Service., 1996). Hence, firstly the symbol structure of EAN barcode is briefly introduced in this section. It is followed by the explanation of 1D-barcode system and the advantages of such system.

I. 1D-barcode structure

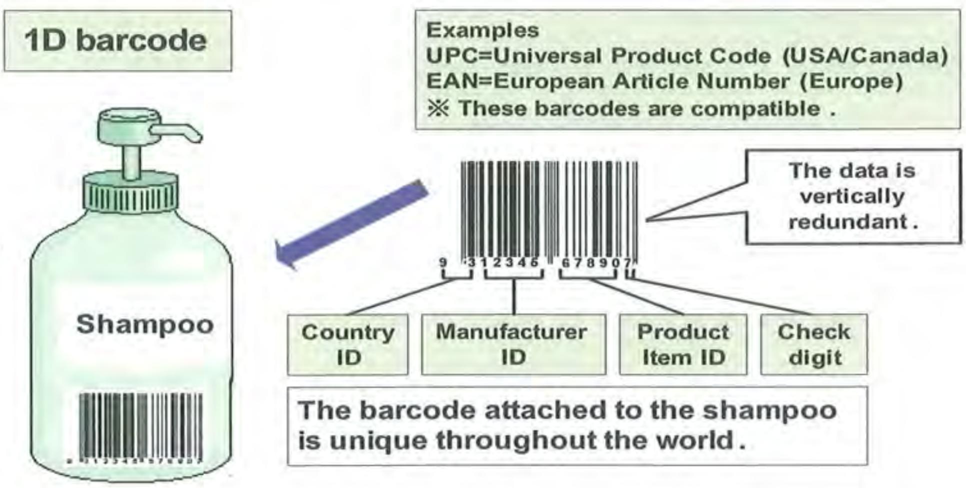
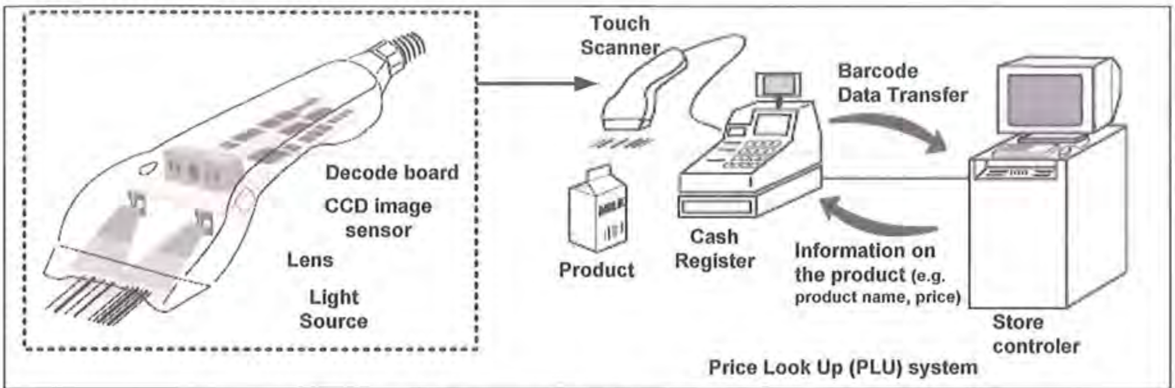


Figure 5: 1D-barcode Structure

A traditional linear bar code is a binary code (i.e.1s and 0s). The lines and spaces are of varying thicknesses and printed in different combinations (LaMoreaux1995). Only up to 13 digits (12 digits for Universal Product Code) can be encoded. These numbers are unique throughout the world and work as a key to databases.

The symbol structure is presented in Figure 5. The first 2 (or 3) digits indicate the country of origin of the product. In the example in Figure 5, the country ID 93 indicates that Australia is the country of origin. The country ID is followed by 5 digits manufacturer ID, and product item ID. The last digit is the check character and is used to detect and prevent symbol decode errors.

II. 1D-barcode system and its advantageous features



Data flow in the PLU System and the structure of a Touch scanner

Figure 6: An example of 1D-barcode System

Source: Barcode Handbook 1. (Technical Corp., n.d.). Retrieved September 5, 2005, from http:// www.technical.or.jp/handbook/

As Figure 6 illustrates, 1D-barcode works as a key to access the database (i.e. Store controller in the Figure 6). The information of the product on which the barcode is attached is stored in and retrieved from the database using the 1D-barcode system. Touch scanner is commonly used in retail stores. The structure of the touch scanner is also illustrated in Figure 6.

Although most 1D-barcodes are capable of encoding only a limited number of digits, it can be seen advantageous especially for the standardization (Tokura, 2002). Unlike, languages, numbers are commonly used in the world, which reduces the complication that should be involved for standardization. In fact, 1D-barcode system resulted in huge success in most interest groups such as grocery manufacturer, wholesaler, and retailer. The distinctive benefits of using 1D-barcode systems are described as follows:

- Fast and accurate keyless data entry is achieved. The probability of 1D-barcode misreading is 1 in 3×10^6 characters.
- Little (or no) employee training is required.
- The numbers encoded into 1D-barcode is globally unique. It is advantageous on sales and inventory management.
- The real-time information can be obtained. This is also useful for both sales and inventory adjustment (Tokura, 2002).

III. Future of 1D-barcode

Although the activity for the utilization of 2D-barcode have been often seen in certain industries, there are little such trend in the field of distribution. That is, it is expected that 1D-barcode system will progress further. This is due to three main factors. First of all, there is no major problem with the current use of standardized 1D-barcodes such as EAN13/8, UPC-A/E, and EAN128 (Japan Automatic Identification Systems Association., 2004). Secondly, the adoption of Reduced Space Symbology (RSS) covers the shortcomings of the existing 1D-barcode in the grocery industry and in healthcare, where items are too small to allow for older barcode symbologies (Adams, 2004). The existing 1D-barcode can encode only up to 13 digits (12 digits in the case of UPC), whereas RSS has a 14-digit data structure (see, Figure 7, p.15). In fact, the new GS1 organization has been formed from EAN International and its 101 local member organizations, including the Uniform Code Council (UCC) from USA (Verlagsgruppe Deutscher Fachverlag., 2005). GS1 is a leading global organisation dedicated to the design and implementation of global standards and solutions to improve the efficiency and visibility of supply and demand chains (GS1., 2005). GS1 took the initiative in carrying out the plan that the 14-digit Global Trade Item Number (GTIN) should be globally adopted and used in product databases since January 1, 2005. The aim is to speed up the data flow in commercial exchanges and to optimize the control of goods (GS1., 2005).

RSS-14 Truncated symbol representing 00012345678905	RSS-14 symbol representing 20012345678909 and a linkage flag of 0
RSS-14 Stacked symbol representing 00012345678905	RSS Expanded symbol representing (01)98898765432106(3202)012345(15)991231

Figure 7: Examples of RSS symbology

The third factor is that it is nearly impossible to establish the new systems for the utilization of 2D-barcodes throughout the world (Verlagsgruppe Deutscher Fachverlag., 2005).

2.2.2 Two Dimensional (2D) Barcode

As has been seen, it is less likely that 2D-barcodes will replace its 1D counterpart. However, it does not depreciate the value of 2D-barcodes. 2D-barcodes combine the advantages of every data-entry method, including portability, readability, and excellent information-carrying capability in a small area (LaMoreaux, 1995). Due to the substantial data carrying ability, 2D-barcodes are sometimes called a portable data file or even portable database. Properly printed, 2D-barcodes can have high readability providing the correct scanner is used. Combined with error detection and correction, they can be also quite secure (Japan Automatic Identification Systems Association., 2004). Especially where the computer database is not available, therefore, 2D-barcodes can be the best trade-off (LaMoreaux, 1995). In addition, these codes can provide a superior solution for fast package sorting where high-speed processing is required or for medical records where the space is a problem (LaMoreaux, 1995).

Although there are some exceptions, two dimensional barcodes can be classified into two broad categories by the fashion that data are encoded and presented: stacked codes and matrix codes (see, Figure 8).

Stacked code	Matrix code
PDF417: Most widely used 2D barcode	Code 1: Earliest public domain matrix code

Figure 8: Stacked code and Matrix code

The former, also known as multi-row code refers to those symbologies that are made up of a series of one dimensional barcodes. In a stacked barcode, the data is coded in a series of bars and spaces of varying widths (Barnes, Bradshaw, Day, Schott, and Wilson, 1999). On the other hands, the data are encoded based on the position of black spots within a matrix for matrix code. Accordingly, the use of stacked 2D-barcodes increase the space to encode the data although they are capable of containing more data compared with the use of 1D counterpart. Matrix codes, on the other hand, can encode much greater amount of data in much smaller space. Hence, matrix symbologies can be regarded as "true 2D" codes (Intermec, cited in Barnes, et al, 1999).

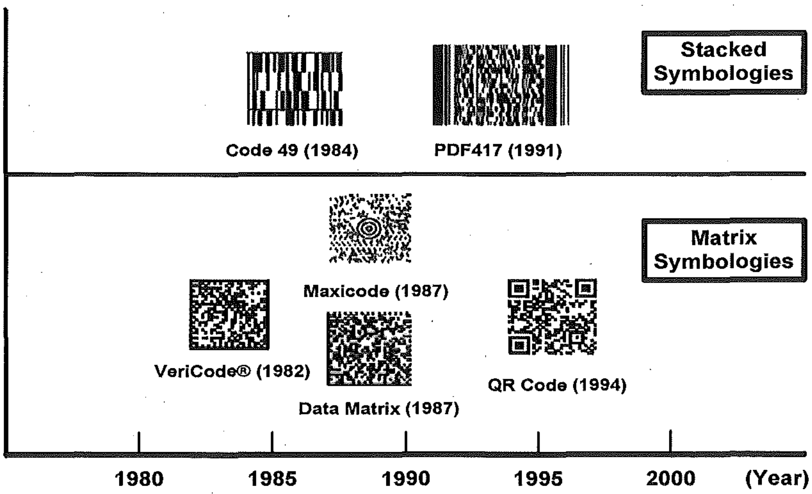


Figure 9: 2D Symbology Development

Source: 2 Dimensional Symbologies Handbook. (KEYENCE CORPORATION., 2005). Retrieved May 13, 2005, from http://www.keyence.co.jp/ req/info/2jigenpdf/show.jsp

The demand to encode more data in limited space led to the 2D-barcode invention. Firstly, the stacked 2D-barcodes were developed to respond mainly to the demand for the greater data capacity, followed by the invention of the matrix codes to handle the space limitation while satisfying the need for the greater data capacity. Figure 9 shows the brief history of the 2D-barcode development.

In addition to the symbol structure, there is major difference between stacked symbology and matrix symbology. That is the scanners used to read the symbols. Stacked 2D-barcodes requires a specialized laser based scanning device such as raster scanners that is capable of reading in two dimensions (i.e. vertically and horizontally, simultaneously) (Barnes, et al, 1999). A raster scanner operates the same way as 1D laser scanner does, emitting the same type of light. However, it is capable of oscillating the beam in two dimensions. Raster scanners are usually equipped with the decoding technology needed to decipher the code when it is damaged (Barnes, et al, 1999). Stacked 2D-barcode can be read with a traditional 1D scanner even though it reduces the time efficiency. The different scanning patterns are presented in Figure 10.

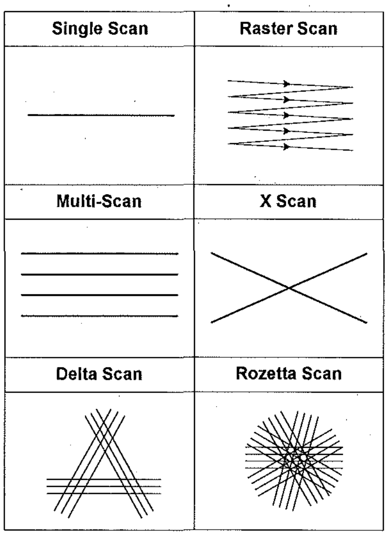


Figure 10: Laser Scanner Scanning Pattern

Source: Tutorial for beginners: Barcode Tutorial for Beginners (Tokura, 2002). Retrieved September 11, 2005, from http://www. jaisa.or.jp/about/kisojirei.html

Raster scanners are viable solution for reading stacked 2D-barcodes. However, they are not capable of deciphering matrix 2D-barcodes as the decoding process of matrix symbologies involves more complicated translation. To read matrix 2D-barcode, consequently, the Charge Coupled Device (CCD) imagers have been developed. With CCD imager, an array of light sensitive elements that are arranged in a square format is used to read a 2D-barcode. Figure 11 shows a CCD imager used to decode 2D-barcodes.

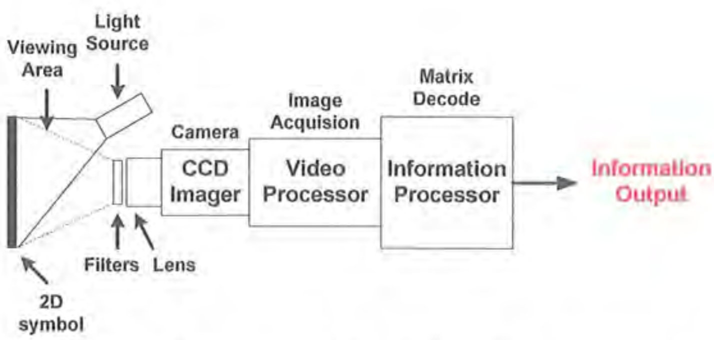


Figure 11: CCD Imager Used to decode 2D-barcodes

Source: Two Dimensional Bar Coding (Barnes, et al, 1999), Retrieved March 04, 2005, from http:// scholar.google.com/scholar?hl=en&lr=&safe=off&q=two+dimensional+bar+ coding %2C +purdue +university

Each 2D-barcode has evolved independently to meet the requirement for certain groups as opposed to 1D-barcode system where the standardization of the symbol and the code structure was the initial purpose to allow the entire system to work effectively.

For example, MaxiCode is of fixed size (1 sq. in.) and can encode only up to 93 characters (alphanumeric) (Japan Automatic Identification Systems Association., 2004) (the symbol description is provided later in this Section). It appears to be very limiting. However, the code is designed as it is to best fit to its application (LaMoreaux, 1995). MaxiCode was developed by United Parcel Service (UPS) for shipping application where high-speed sorting is required. If the central bull's eye were of variable size, searching for it would be much more complex. In addition, if the cell size of symbols were smaller, the individual hexagons would not be resolvable without increasing reader resolution. For example, doubling the resolution for the same belt width would increase fourfold the number of samples per second (LaMoreaux, 1995).

A company may choose a stacked 2D-barcode for the system unless the space is a problem. On the other hand, it is more likely that semi-conductor manufacturer select a matrix code due to the space limitation of products.

Unlike the distribution systems, global information exchange may not be the first priority in certain industries. The systems work effectively as long as the groups with the common interest use the same code structure. It may explain the trend of 2D-barcode development.

2.2.3 Three Dimensional (3D) Barcode

Since 3D image cannot be captured by camera phone, 3D-barcode technology is out of the scope in this study. For the completeness of the study, however, a brief explanation on 3D-barcodes is provided.

3D barcode (Bumpy Barcode) is in fact any linear (1D) barcode that is embossed on a surface (Adams, 2004). Symbols are those marks that are created to utilize their relief or "bumpy" aspect to determine the positions and widths of the bars and spaces, rather than their visual contrast (Mecco Partners LLC., 2005) (see, Figure 12). They can be painted, coated or made a permanent feature of a part, keeping their readability (Adams, 2004).

Figure 12: 3D (Bumpy) barcodes

Source: Bar Code1. (Adams, 2004). Retrieved September 25, 2005, from, http://www.adams1.com/pub/russadam/stack.htm

2.3 Two Dimensional Symbologies

2D-barcodes share the features within the same type of code: stacked and matrix. Both stacked 2D-barcodes and matrix 2D-barcodes are further classified by their ownership domain: public and proprietary. In this section, brief explanations of currently used 2D-barcodes are provided starting with stacked 2D-barcodes (see, Table 1 below), then matrix 2D-barcode (see, Table 2, p.27), which are followed by the introduction of 2D-barcodes that are used for camera phone applications (see Figure 13, p.35). It should be noted that all the 2D-barcodes explained in this section would be examined as sample codes for the main purpose of this study: standardization.

2.3.1 Stacked 2D-barcodes

Table 1: Stacked 2D-barcodes

Public Domain		Proprietary		Others※	
Code 49		Datastrip Code		Codablock	
PDF 417 Micro PDF417				CodablockF	
SuperCode				Code 16K	

※ 2D-barcodes whose ownership domain is unknown are placed under the name of others

Stacked 2D-barcodes belong to public domain are presented firstly, followed by those in proprietary domain, and the others.

I. Symbologies in Public Domain

Code 49

Code 49 is the first truly two dimensional barcode that is introduced by Intermec Corporation. The code was developed by David Allais in 1987. Code 49 is constructed by a series of barcode symbols stacked one on top of another. Each row consists of a leading quite zone, a starting pattern, 4 data words encoding 8, with the last character a row check character, a stop pattern, and a trailing quiet zone. Each row encodes the data in exactly 18 bars and 17 spaces and is separated by a one module high separator. The code is continuous, variable-length symbology that can encode the complete ASCII128-character set.

Modified moving beam laser scanners or CCD scanners are used for reading Code 49.

PDF 417

Portable Data File (PDF) 417 is most widely used stacked 2D-barcode and its popularity is global (Japan Automatic Identification Systems Association, 2004). The code was invented by Ynjiun Wang in 1991 at Symbol Technology (Barnes, et al, 1999). PDF 417 symbol is made up of 17 modules arranged into 4 bars and spaces; this gives rise to the name of the symbology. One PDF 417 symbol is capable of encoding more than 1100 bytes, 1800 ASCII characters or 2700 digits, depending on the selected data-correction mode (LaMoreaux, 1995). Every PDF 417 symbol consists of a stack of rows, from a minimum of 3 to a maximum of 90 rows. Each PDF 417 row contains start and stop patterns, left and right row indicators, and from 1 to 30 data symbol characters.

PDF 417 can be scanned by linear scanners mastering laser scanner or CCD scanners. As the number of rows and their length are selectable, the aspect ratio of a PDF 417 symbol can be varied to suit spatial requirements for printing (LaMoreaux, 1995).

Micro PDF 417

Micro PDF 417 is a multi-row symbology, derived from and closely based on PDF 417. Micro PDF 417 is designed for applications where improved space efficiency is required (Bushnell& Meyers, 1999). The symbol allows up to 150 bytes, 250 alphanumeric characters, or 366 numeric digits to be stored by specifying one of the three compaction modes: data, text or numeric.

SuperCode

SuperCode, which was also developed by Ynjiun Wang 1994, uses a packet structure (Barnes, et al, 1999). The packet structure of SuperCode ensures that each symbol character that encodes a data or error correction codeword is adjacent to a symbol character that has the packet address. Hence, it is not necessary for the packets to be physically abutting one another. This allows great flexibility in placing packets, which in turn enables non-rectangular symbol shapes (Barnes, et al, 1999).

SuperCode performs error correction based on Reed-Solomon error correction algorithms, which can be used to correct errors as well as detect them. There are 32 error correction levels and a user can select the level according to their operating environment. The maximum number of data characters per symbol at the lowest level of error correction is 4,083 alphanumeric, 5,102 digits, or 2,546 bytes (Barnes, et al, 1999).

II. Symbologies in Proprietary Domain

Datastrip Code

Datastrip Code, which is the oldest 2D symbology, was developed by Softstrip Systems and was originally called Softstrip. Currently the symbol is owned by Datastrip Inc. Datastrip's patented encoding and scanning system allows not only data, graphics, but also digitized sound to be printed on plain paper in a highly condensed format.

A Datastrip Code is composed of a matrix pattern, comprising very small, rectangular black and white areas (or DiBits). Markers down the side and across the top of the strip (start line, checkerboard and rack) contain alignment information for the Datastrip Code readers and it ensures the data integrity (Barnes, et al, 1999). Datastrip Code offers outstanding reliability and error correction capabilities, including parity bits on each encoded line. The code is tolerant to wear and tear and cannot be fraudulently produced or altered once it is printed (S. Coutin, personal communication, July 13, 2005).

Datastrips are typically up to 5/8 of an inch wide and up to 9 inches long (Barnes, et al, 1999). Datastrip Code is capable of storing up to 4,425 bytes of data (S. Coutin, personal communication, July 13, 2005). The data density of the code varies depending on the printing technology used to produce the strip. Low-density strip (up to 1,100 bytes per 9-ince strip) can be produced on most dot matrix printers and strips containing up to 3,500 bytes by using laser printing technology. More sophisticated production methods that use photographic techniques are required to produce high-density strips (up to 4,800 bytes).

Datastrip Code must be read by special readers from Datastrip Inc. and the reader must be in contact with the codes (Barnes, et al, 1999). The code is now of most interest for dealing with biometric data, e.g. photo, fingerprint, signature and text (S. Coutin, personal communication, July 13, 2005).

III. Others

Codablock

Codablock from ICS Identcode-System is invented by Heinrich Oehlmann. It was originally a stack of Code 39 symbols.

Each Codablock symbol, which contains from 1 to 22 rows, has a start and stop bar group that extends the height of the symbol and also a two character row indicator. Each row can contain a variable amount of characters, depending on the x-dimension of the symbol. The last row of the symbol has an optional check digit.

The code is continuous, variable-length symbology. It can encode the Code 39 character set (i.e. 10 digits, 26 letters, space, and 6 symbols), and is no more dense than a Code 39 symbol at a given print density (Barnes, et al, 1999). Not only the number of rows needed, but also the number of characters per row and the print density must be calculated to best fit the data into the Codablock symbol.

Codablock was adopted by German blood banks for the identification of blood.

CodablockF

Codablock F is basically a stack of Code 128 symbols. A Codablock F symbol is composed of between 2 and 44 rows, each up to a maximum of 62 symbol characters wide (Barnes, et al, 1999). Each row contains additional overhead information relating to row numbering and symbol size, which enables the decoded output from each row to be re-assembled in the right sequence and reproduce the complete message.

Each row can be read by a standard Code 128 reader and the code as a whole can be read by moving bean laser scanners with very little modification.

Code 16K

In 1989, Code 16K was developed by Ted Williams, who also invented Code 128. Accordingly, the structure of 16K is based on Code 128. The name derived from squared 128 (i.e. 16,000 or 16K) (Barnes, et al, 1999). The development of Code 16K provided a solution for an inherent problem with Code 49 whose structure requires a large amount of memory for encoding and decoding tables and algorithms.

Each Code 16K symbol contains between 2 and 16 rows, with 5 ASCII characters per row. In addition, up to 107 16-row symbols can be concatenated together to enable up to 8,025 ASCII characters, or 16,050 numeric digits encoding. In extended mode, the first three characters in each row symbol have information about the order of the 16 row symbol in the block, and the total number of symbols in the block. The code is a continuous, variable-length symbology that can encode the complete ASCII 128-character set.

Code 16K can be read by modified moving beam scanner or CCD scanners in any order. A bar code reader automatically puts the information in right sequence after the last row is scanned. Standard printing technology is used to print Code 16K.

2.3.2 Matrix 2D-barcodes

Table 2: Matrix 2D-barcodes

Public Domain		Proprietary			
Aztec Code (Small Aztec Code)		3-DI		INTACTA. CODE	
Code 1		ArrarTag		MiniCode	
MaxiCode (UPSCode)		CP Code (Communication Platform Code)		SmartCode	No image is available
				Snowflake Code	
Ultracode		DataGlyphs		Others※	
				Dot Code A (Philips Dot Code)	
		HueCode	No image is available	Secure 2D Code	

※ 2D-barcodes whose ownership domain is unknown are placed under the name of others

Table 2 shows matrix symbologies. Each symbol is described in the order presented in Table 2.

I. Symbologies in Public Domain

Aztec Code

Aztec Code was invented by Andy Longacre of Welch Allyn Inc. in 1995. The code is developed to provide ease-of-printing and ease-of-decoding. The symbol size varies, with the smallest of 15 × 15 square and the largest of 151 × 151. The minimum data capacity of Aztec code is 13 numeric or 12 alphabetic characters, whereas the maximum of 3,832 numeric, 3,067 alphabetic characters, or 1914 bytes of data can be encoded. There are a total of 32 different symbol sizes available, with user selected amount of Reed-Solomon error encoding from 5 % to 95 % of data region (Barnes, et al, 1999). Aztec Code can encode all 8-bit values: values 0 - 127 are interpreted as the ASCII character set whereas values 128 - 255 are interpreted as ISO 8859-1, Latin Alphabet No. 1.

Small Aztec Code

Small Aztec Code is a special space-saving version of Aztec Code for encoding shorter messages (up to 512 bits of data, i.e. typically about 95 characters or 120 digits). Space is saved by removing one set of rings from the finder pattern, eliminating the reference grid, and using a shorter mode message which limits the symbols to four data layers

Code 1

Code 1 was invented by Ted Williams in 1992 and is the one of the earliest public domain matrix symbologies. The horizontal and vertical bars crossing the middle of the symbol is the finder pattern of the symbol. The symbol is capable of encoding ASCII data, error correction data, function characters, and binary encoded data. 8 different sizes are available, ranging from Code 1A to Code 1H. Code 1A can hold up to 22 digits or 13 alphanumeric characters, whereas Code 1H can hold the maximum of 3,550 digits or 2,218 alphanumeric characters. The largest symbol version measures 134 × wide by 148 × high. The code is flexible in its shape and can be made into many different shapes such as an L, U, or T form.

MaxiCode (UPSCode)

MaxiCode, originally called UPS Code, is created by United Parcel Service in 1992 for high-speed sorting and tracking of unit loads and transport packages. MaxiCode is ideal for applications where the label is on a moving package, its orientation is random, space is limited, and the scanner is placed so a large view of the package is taken (LaMoreaux, 1995). It packs a lot of information in a small space: 100 characters of data in 1 square inch.

Rather than being made up of a series of square dots, the symbol is composed of a central bull's eye surrounded by 1-inch by 1-inch array of 866 black interlocking hexagonal shapes (LaMoreaux, 1995). The bull's eye helps the scanner locate the code regardless of its orientation.

MaxiCode is 15% denser than square dot codes due to its symbol structure. By using CCD camera or laser scanner, the symbol can be read even if up to 25% of the code is damaged (LaMoreaux, 1995). However, the symbol must be printed by high-resolution printers such as thermal transfer printers. Built-in Reed-Solomon error correction is part of the code.

Ultracode

Ultracode, which was invented by Zebra Technologies, is composed of a variable-length strip of pixel columns with non-critical widths. The code includes numeric and alphanumeric modes, with advanced language/code page that handles provisions and selectable levels of Reed-Solomon error correction. Both black/white and a higher density coloured version are supported. The symbology utilizes pairs of vertical columns of either 7 monochrome (dark/light) or 8 multicoloured (typically white, red, green, and blue, or cyan, magenta, yellow and black) cells to encode each datum (i.e. a fact or piece of information) as a point on character planes of a 43 plane language group.

The Ultracode symbologies differ from most 2D, error-correcting bar codes in that they have a long, thin aspect ratio similar to existing linear bar codes and are not positioned as high-capacity symbologies. Ultracode is especially suited for direct printing with low linear precision.

II. Symbologies in Proprietary Domain

3-DI

3-DI, which was developed by Lynn Ltd, uses small circular symbols. It is most suited for identification marks on shiny, curved metal surfaces such as surgical instruments.

ArrayTag

ArrayTag was invented by Dr. Warren D. Little of the University of Victoria. The symbol is composed of elemental hexagonal symbols with a patented complementing border which are printed either alone or in sequenced groups. ArrayTags, which can encode hundreds of characters and can be read at distances up to 50 meters, is optimized for reading at a distance or in variable lighting situations. The principle application of the code is to track logs and lumber.

CP Code
(Communication Platform Code)

CP Code was developed by CP Tron, Inc. The symbol, which consists of square matrix symbols with an L-shaped peripheral finder and adjacent timing marks, is visually similar to Data Matrix Code (Verutec Iconix Ventures Inc., n.d.). CP Code can be read at any angle and also from the back. The symbol has error detection and correction capability by using Reed-Solomon algorithms (Verutec Iconix Ventures Inc., n.d.).

DataGlyphs

DataGlyphs is lattice (categorised into matrix code) symbology developed by Xerox PARC in 1989 (J.Breidenbach, Research Staff, Palo Alto Research Center (PARC), personal communication, June 29, 2005). The code is made up of a grey background pattern of small " \ "s and "/"s encoding binary data, including synchronization patterns and error correction. Each mark can be as short as 1/100th of an inch (0.25mm), which makes it possible to produce a symbol with densities of 1000 8-bit "bytes" per square inch. The adjustable, internal error correction and randomization of the data allow DataGlyphs to be tolerant to ink marks, bad copies, and even staples through the symbol.

DataGlyphs offer binary data storage and thus can support any language or character set (J.Breidenbach, Research Staff, Palo Alto Research Center (PARC), personal communication, June 29, 2005).

The code can be read omni-directionally with low contrast and no quiet zone is required for reading the code (J.Breidenbach, Research Staff, Palo Alto Research Center (PARC), personal communication, June 29, 2005). DataGlyphs are designed to merge with the design of the product they are printed on and thus can be logos or tints behind text or graphics. Applications include questionnaires, direct-mail reply forms and surveys, and business cards. The symbol is read using an image scanner.

Security is not built into symbology. However, users can digitally sign or encrypt data before storing it (J.Breidenbach, Research Staff, Palo Alto Research Center (PARC), personal communication, June 29, 2005).

hueCode™

hueCode, which is invented by Harry Shamir in Robot Design Associates in 1995 (H.Shamir, Inventor of hueCode™, personal communication, June 28, 2005). The code consists of blocks of cells containing more than one bit per cell. This can be achieved by using shades of grey or colour. The symbol can be printed on any medium such as photo film, plastic surface (e.g. CD/DVD), or so forth (H.Shamir, Inventor of hueCode™, personal communication, June 28, 2005).

hueCode™ will generate the absolute highest information density under any given set of conditions of paper, ink, scanning system etc (H.Shamir, Inventor of hueCode™, personal communication, June 28, 2005).

Information densities vary range between under 640 bytes per square inch using laser printers to over 40,000 bytes per square inch using dye sublimation printers. It is dependent on the specific techniques used, but hueCode™ is read using a flatbed scanner set to 400 × 400 dpi and proprietary software. The code is intended to store text information on the backs of business cards or medical cards.

INTACTA.CODE™

INTACTA.CODE™, which was developed by INTACTA Technologies, Inc., can take any binary data such as executable files, video, text, and audio (or a combination of files). It then applies INTACTA.CODE™ compression, encoding, and error correction engines to create an envelope for the data. The envelope enables the data to be distributed securely while maintaining the integrity of the format and the content. More detailed information about INTACTA.CODE™ is presented in Section 4.

MiniCode

MiniCode developed by Omniplanar, Inc. is made up of square matrix symbols with a patented method of encoding both low-resolution data (tracking/sorting applications), and high-resolution data (shipping manifest applications).

SmartCode

SmartCode is developed by InfoImaging Technologies. The code consists of a large printed array of binary bits that encodes data files. The code is suitable for either page scanning and decoding, or direct fax transmissions.

Snowflake Code

Snowflake Code, which was developed by Electronic Automation Ltd. in 1981, was acquired in March 1999 by Videojet Systems International Inc., a division of Marconi Data Systems Inc.

Similar to Philips "Dot Code", the code is a square array of discrete dots and is possible to encode more than 100 numeric digits in a space of only 5mm x 5mm. User selectable error correction allows up to 40% of the code to be destroyed and still remain readable.

The advantageous feature of the code is that it can be applied to products and materials in a wide variety of ways, including printed labels, ink-jet printing, laser-etching, indenting or hole punching. The symbol is used in the pharmaceutical industry.

III. Others

Dot Code A

(Philips Dot Code)

Dot Code A (also known as Philips Dot Code) is one of a limited number of dot code symbologies. This symbology was designed for unique identification of objects in a relatively small area, or for direct marking by low precision marking technologies. The symbol is composed of a square array of dots ranging from 6 × 6, to 12 × 12, the latter enabling over 42 billion individual items to be distinguished. Applications include the identification of laboratory glassware and the marking of laundry.

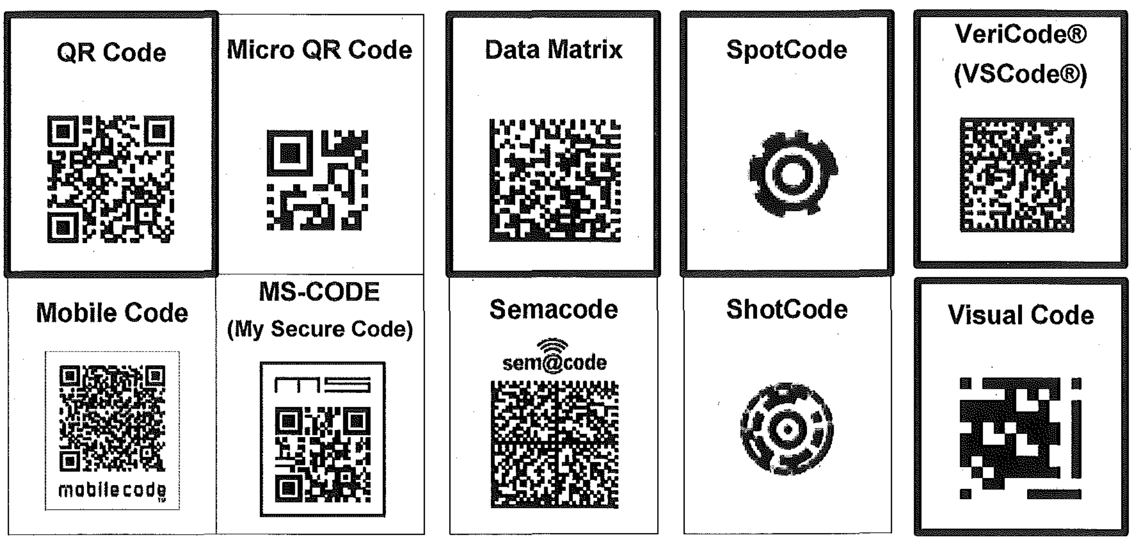
Secure 2D Code

Secure 2D code was invented by Chung-Tsai Yeh and Ling-Hwei Chen in 1997. As the symbol name depicts, Secure 2D code emphasizes security and error correction (Yeh, & Chen, 1998). To enhance the security of the code, the input data is divided into two parts: general and secret. Firstly, the general data is transformed into a 2D code pattern, and then secret data is hidden in the 2D code pattern (Yeh, & Chen, 1998). Detailed information of Secure 2D code is presented in Section 4.

Note: The introduced 2D-barcodes were consulted for full information provided by BarCode1. (Adams, 2004), unless otherwise indicated.

2.3.3 Two Dimensional Barcodes and their Derivatives used for Mobile Applications

Figure 13 illustrates 2D-barcodes and their derivatives that are utilized for mobile phone application. All symbols are classified into Matrix code. QR Code, Data Matrix, and their derivatives belong to public domain, whereas VeriCode® and VSCode® are proprietary symbols. Ownership of ShotCode (SpotCode) and Visual Code are unknown since both codes have been developed recently. Original 2D-barcodes are presented in the boxes with thick borders in Figure 13. As VeriCode® and VSCode® have the same symbol structure except for their data capacity, only VeriCode® is shown in Figure 13. Each code is addressed to the detail in Section 3.



Note: Each original 2D-barcode is presented in the box with thick borders.

Figure 13: 2D- barcodes and their Derivatives used for Mobile Applications

2.4 Summary

There are different types of keyless data entry/automatic identification systems such as Optical Character Recognition (OCR) system, Radio Frequency Identification (RFID) systems, magnetic stripe technology as well as barcode technology. One of the most distinctive advantages of the barcode use is its inexpensive operation.

At present three different types of barcode exist: 1D, 2D and 3D barcode. The first two, especially 1D-barcode, has been globally used. One of the distinctive differences between 1D-barcode and 2D-barcode is their data capacity. 1D-barcode can encode only a limited number of digits, alphanumeric characters, and special characters, whereas its 2D counterpart that has much higher data capacity. 1D-barcode is merely a key to the database, whereas 2D-barcode can work as a portable database.

There is another difference between 1D-barcode and 2D-barcode that is worthy of special mention. 2D-barcodes were independently developed in response to the demand from certain industries. Mean while, 1D code/symbol selection was based on the fact that all the interest groups use the same symbol structure and each code can be uniquely identified. That is, 1D-barcode was developed with the intention of global use. Hence, despite its shortcoming in data capacity, 1D-barcode has been widely accepted throughout the world and presumably the trend will continue.

Recently, mobile phones equipped with CCD cameras have gained great popularity. The integration of camera phone and 2D-barcode technology has opened a door for new general user applications development. In addition to the great potentials in application development, another meaningful outcome the integration of these two technologies is that 2D symbols can be recorded on re-writable mediums such as mobile phone displays and memories.

Barcode technology, just as other automatic identification technologies, has a great chance of further growth, each supplementing another's shortcomings.

3 Two Dimensional Barcodes for Mobile Phones

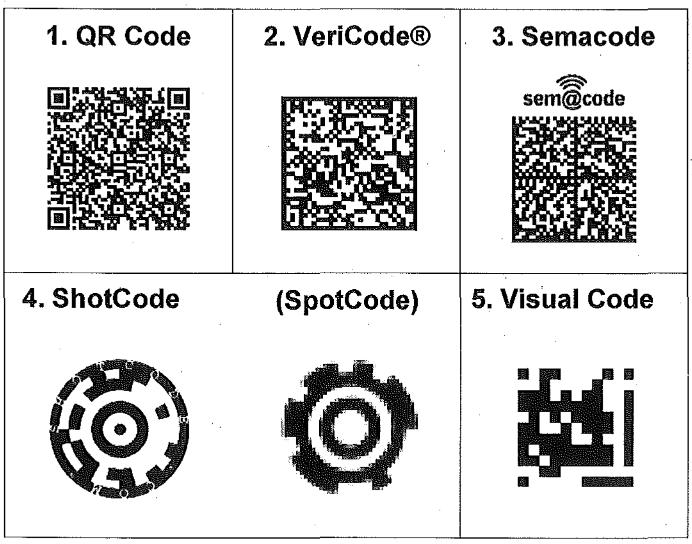


Figure 14: 2D-barcodes utilized for mobile phone applications

As mentioned previously, mobile phones with a camera function are capable of image capturing and processing tasks. Hence, some new 2D-barcodes have been invented, targeting camera phone users.

Visual code is an example of such inventions (Rohs, 2004). (see, Figure 14-5). Examples of derivatives from the existing 2D-barcodes are Semacode and ShotCode (originally invented as SpotCode by High Energy Magic Ltd. and sold to OP3 AB Sweden) (see, Figure 14-3 and 14-4, respectively). While the former has adapted Data Matrix barcode format, the latter has been created based on TRIPcode (Target Recognition using Image Processing code) (Rohs, 2004). Beside applications for a variety of industries, general 2D-barcodes such as Quick Response (QR) Code and VeriCode® (see, Figure 14-1 and 14-2, respectively) have also been used to develop applications that target general users of camera phones.

The 2D-barcodes illustrated in Figure 14 have been widely utilized for mobile specific applications. Thus, it may be a good idea to examine these 2D-barcodes and their widely accepted applications for deriving the criteria to determine the 2D-barcode that is optimized for use with camera-enabled mobile phones. These 2D-barcodes are presented in the order the codes were shown in Figure 14.

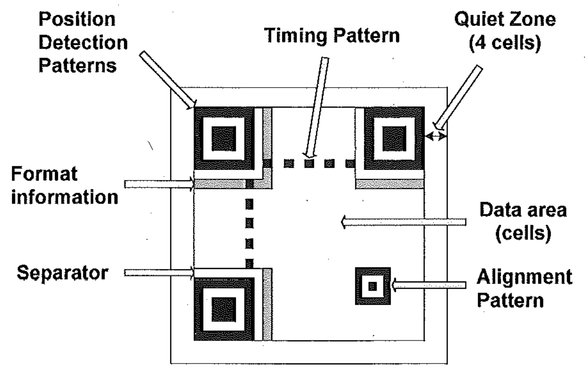
3.1 QR Code

QR Code is developed by Denso Wave (a division of Denso Corporation at the time) in 1994 (DENSO WAVE INCORPORATED., 2003). QR Code is a two dimensional matrix symbology that have position detection patterns on three corners. The symbol name is derived from Quick Response (QR) code and, as the name depicts, is initially designed for ultra high speed reading as well as omni-directional reading (KEYENCE CORPORATION., 2005). That is, QR Code is developed to improve reading speed of complex-structured 2D-barcodes. QR Code is also known for its capability of direct encoding Kanji–Kana character sets. Other QR Code features are mass data capacity, high data density, and selectable levels of error correction ability (Bushnell & Meyers, 1999). Recently derivatives of QR Code have been developed. Mobile Code and MS-CODE are examples of such 2D-barcodes.

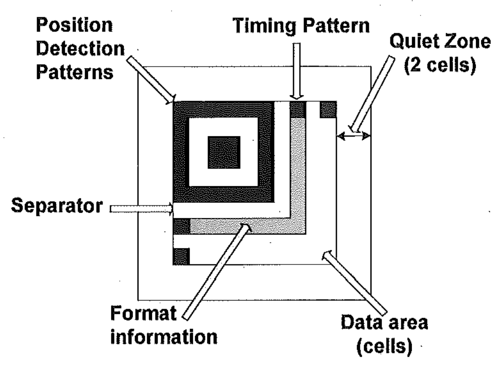
In August 2002, in Japan, J-SH09 (manufacturer: Sharp, carrier: J-phone) was released as the first mobile phone that has a reader for Japanese Article Number (JAN) code (1D-barcode) and QR code (2D-barcode) as one of its functions (Saitou, 2002). Many other Japanese phone companies such as DoCoMo, Vodafone, and au (also known as KDDI) started offering mobile phones with the ability to read QR Code (Saitou, 2002) since J-SH09 opened the door for applications in which a 2D-barcode is utilized.

3.1.1 QR Code Symbol Structure

QR code



Micro QR Code



Both QR Code and Micro QR Code consist of 7 elements: position detection (finder) pattern, timing pattern, alignment pattern, format information, separator, data area and quiet zone. There are difference between QR Code and Micro QR Code mainly on two points:

- Position Detection Pattern:
  QR Code – at the 3 corners,
  Micro QR Code – at 1 corner.
- Quiet Zone:
  QR Code – A four-module wide margin at all sides of a symbol,
  Micro QR Code – A two-module wide margin at all side of a symbol.

Figure 15: QR Code Micro QR Code Symbol Structure

Source: 2 Dimensional Symbologies Handbook (KEYENCE CORPORATION., 2005). http://www.keyence. co.jp/ req/info/2jigenpdf/show.jsp

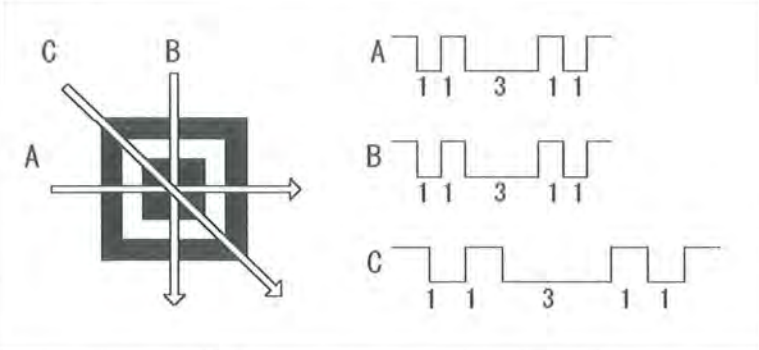
Figure 15 shows the code structure of QR Code. QR Code is composed of two main parts: function patterns and encode area. Function patterns include finder patterns, timing pattern, alignment pattern and quiet zone. Finder patterns are usually called position detection pattern and located at the 3 corners of the symbol. Timing patterns are broken borders placed between the finder patterns. Alignment patterns are assigned within the code area in the fixed ratio and each pattern has an isolated cell. Each symbol is surrounded by a four-module wide quiet zone (a two-module wide for Micro QR Code). Function patterns are used to define firstly the accurate position of the symbol, then symbol size, its orientation, and the whole picture of the symbol.

On the other hand, the encode area is mainly made up of data field including Reed-Solomon codes as well as raw data and format information that comprises the error correction level, mask number, and so forth.

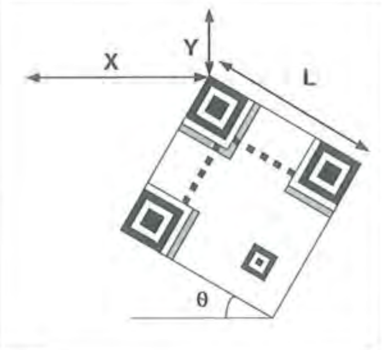
I. Position Detection Pattern (finder Pattern)

Position detection patterns at the 3 corners of the symbol are one of the most distinctive features of QR Code. When scanned, the detection patterns are firstly detected by the reader, which locate the position of the code in ultra-speed.

The ratio of the black and white on a line that passes the centre of the finder pattern (i.e. B:W:B:W:B) is 1:1:3:1:1 in any angle (see, Figure 16- i , p.42). This unique ratio of black and white enables the considerably fast detection of the 3 finder patterns in the symbol. Once the position of the symbol (i.e. finder patterns) is located, the code size (L), tilt (θ), and orientation are calculated based on the position of the three finder patterns found (see, Figure16- ii). Hence, the finder patterns also enable the symbol to be read omni-directionally.



i : The ratio of black and white areas in the finder pattern. The position detection based on the black and white ratio in the pattern is the key mechanism for the stable high-speed reading of QR Code.



ii : Elements to be used for the determination of the size and orientation of the symbol.

Figure 16: Elements used for the position detection,

size, and orientation of the symbol

Source: Understanding 2D Symbologies: Detailed Information on Barcodes (Japan Automatic Identification Systems Association, 2004), Tokyo: Ohmsha

II. Timing Pattern

Timing patterns are vertical and horizontal broken borders that are placed between finder patterns (see, Figure 17). They are used to modify the centre of the coordinates of each cell distortion and/or changes in the ratio between the cells are found (Japan Automatic Identification Systems Association, 2004)

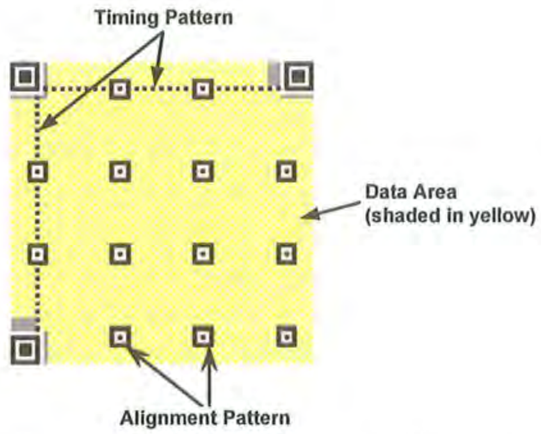


Figure 17: Timing pattern, alignment pattern and data area

Source: New Work Item Proposal Micro QR Code. Inclusion to ISO/IEC 18004 QR Code (ISO/IEC SC 31 National Body of Japan, 2003). Retrieved October 13, 2005, from http://isotc.iso.org/livelink/livelink

III. Alignment Pattern

Alignment pattern enables the correction of the local distortion (ISO/IEC SC 31 National Body of Japan, 2003). This can be achieved by determining the centre of the coordinate in the alignment pattern. An isolated cell is allocated in each alignment pattern, which escalates the detection of the centre of the coordinates.

IV. Format Information

Format information indicates the error correction level and mask pattern used for the symbol. Therefore, this area is the place to be first read in the whole decoding process. Mask pattern will be explained to the detail in the advantageous features section.

V. Data Area

The data area is the area where the original data are encoded (see Figure 15, p.40 and Figure 17, p.42). Not only the raw data but also Reed-Solomon codes are encoded in this area. Reed-Solomon code is a mathematical error correction method used for music CDs etc. The technology was originally developed as a measure against communication noise for artificial satellites and planetary probes. It is capable of making a correction at the byte level, and is suitable for concentrated burst errors (DENSO WAVE INCORPORATED., 2003).

VI. Quiet Zone (margin)

QR Code requires a four-module wide margin at all sides of the symbol (a two-module wide margin for Micro QR Code). This area allows the symbol to be distinguished from the background, which leads to the accurate, high-speed reading.

3.1.2 Symbol Description

I. Code models

Three different models of QR Code exist: Model 1, Model 2, and Micro QR Code (see, Figure 18).

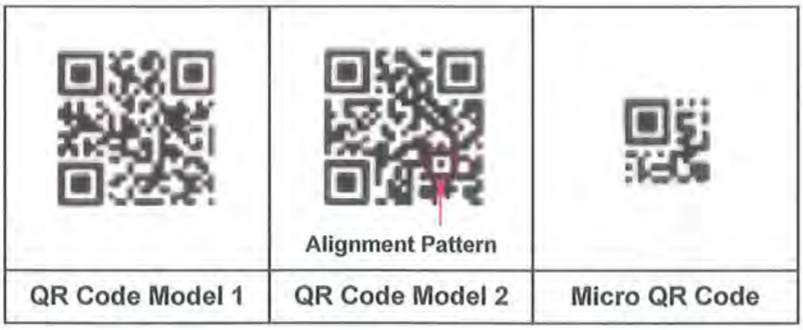


Figure 18: QR Code Models

QR Code Model 1 is the original QR Code and the other two models are derivatives of the Model 1 (KEYENCE CORPORATION., 2005). There are 14 different versions in QR Code Model 1: from Version 1 to Version 14 and they have been approved as AIM International (Automatic Identification Manufacturers International = AIMI) standard.

In order to improve the resistance against distortion, alignment patterns are added to QR Code Model 1 (KEYENCE CORPORATION., 2005). The outcome is called QR Code Model 2. QR Code Model 2 includes 40 versions (from Version 1 to Version 40) and all the versions have been approved as AIMI standard.

Micro QR Code is a small-sized QR Code that fits applications where a smaller space and smaller amount of data are required (DENSO WAVE INCORPORATED., 2003). Minimum symbol size of the Micro QR Code is as small as 11 × 11 (cells) in contrast to QR Codes whose minimum symbol size is nearly twice as large as Micro QR Code; 21 × 21 (cells).

II. Symbol Version

The black and white dots that make up QR Code are called modules. The symbol versions of QR Code range from Version 1 (21 × 21 modules) to Version 40 (177 × 177 modules) (DENSO WAVE INCORPORATED., 2003). Each version has a different module configuration or number of modules. Four modules are added in each side as the version rises (see, Figure 19).

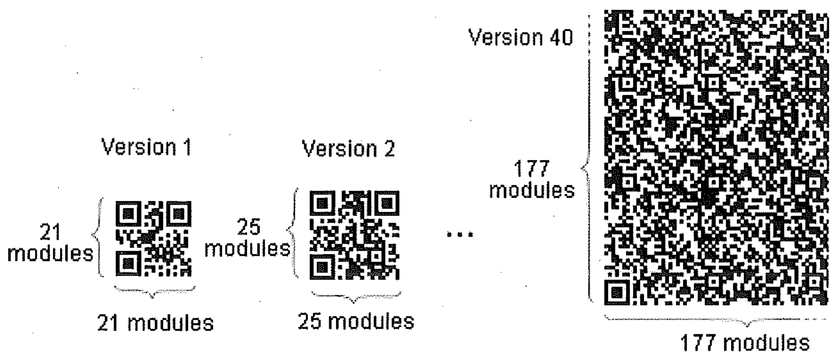


Figure 19: QR Code Version

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003).
from, http://www.denso-wave.com/qrcode/index-e.html

The maximum data capacity for each QR Code symbol version is determined in accordance with the amount of data needed, character type, and error correction level. Each QR Code symbol version has the maximum data capacity according to the amount of data, character type and error correction level. Table 24, 25, 26, and 27 show maximum data capacity for each version (see, Appendix 3, p.161-164).

III. Error Correction

QR Code has error correction capability to restore data in case the code is dirty or damaged. The error correction is implemented by adding Reed-Solomon code to the original data. As presented in Table 3, four different error correction levels are available:

Level L (approx.7%), M (approx. 15%), Q (approx. 25%) and H (approx. 30%). Users have choice according to their need and the operating environment. Higher error correction level improves error correction capability but also increases the amount of data, which results in bigger symbol size. Level M (15%) is most frequently selected.

QR Code Error Correction Capability	
Level L	Approx 7%
Level M	Approx. 15%
Level Q	Approx. 25%
Level H	Approx. 30%

Table 3: Data Restoration Rate for Total Codewords ※

※Codeword is a unit that constructs the data area.
One codeword of QR Code is equal to 8 bits.
Source: 2 Dimensional Symbologies Handbook (KEYENCE CORPORATION., 2005). http://www.keyence. co.jp/ req/info/2jigenpdf/show.jsp

The error correction level should be chosen depending on how much data need to be corrected. For example, when 50 out of 100 codewords of QR Code need to be corrected, 100 codewords of Reed-Solomon code are required, as Reed-Solomon code requires twice the amount of codewords to be corrected. Hence, the total codewords become 200. That is, 50 codewords out of 200 can be corrected. It brings 25 % error correction rate against the total codewords and thus corresponds to QR Code error correction Level Q.

IV. Symbol size

The actual size of the QR Code symbol is determined depending on the millimetre size of the module (one square area comprising QR code, also known as cell) to be printed (DENSO WAVE INCORPORATED., 2003). As the module size increases, the code becomes the more stable and easier to be read with the scanner. It is recommended, therefore, that QR Code symbols be printed as large as possible within the available printing area. However, the increase in size of the symbology requires the wider printing area. It is important, therefore, to select the right module size considering all the relevant factors (DENSO WAVE INCORPORATED., 2003). Figure 20 shows the symbol outcomes with the different module size and factors to determine the code size. An example of QR Code area calculation is provided in Figure 21.

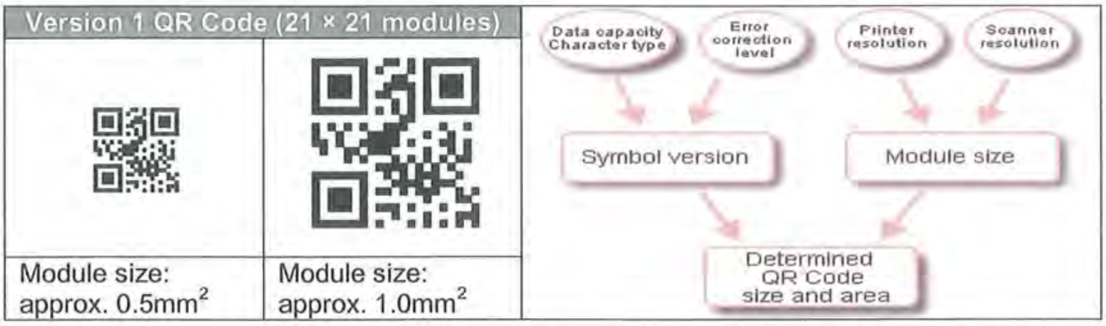


Figure 20: Symbols with different cell size and Symbol Size Decision Factors

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003). Retrieved October, 7, 2005, from http://www.denso-wave.com/qrcode/qrgene4-e.html

<u>Calculation for QR Code that encodes 50 alphanumeric characters with margin</u>

I. Specify the error correction level as the standard "M".

II. Obtain a version from the Version and maximum data capacity table (find the intersection of alphanumeric characters and Level M). → Version 3 capable of storing 50 or more characters. (Version 2 with Level M holds only 38 characters.)

III. Use a printer with 400 dpi resolution. → 0.254 mm when printed with 4-dot configuration.(Equation: 25.4 mm/inch ÷ 400 dpi × 4 dots/module = 0.254 mm/module)

IV. Version 3 = 29 modules, therefore, the size of QR Code is 29 modules × 0.254 mm/module = 7.366 mm.

V. Secure a four-module wide margin. 7.366mm + 0.254mm/module × 8 modules =9.398mm

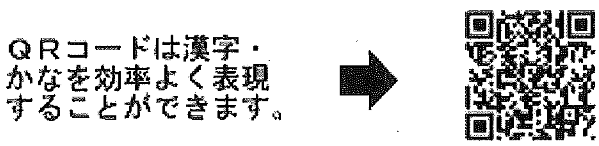
<u>Hence, the required QR Code area is 9.398mm^2</u>

Figure 21: An example of calculation of the area needed for placing QR Code

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003). Retrieved October, 7, 2005, from http://www.denso-wave.com/qrcode/qrgene4-e.html

V. Encodable character set

QR Code is capable of encoding all types of data, such as numeric and alphanumeric, Japanese Kanji, Kana, Hiragana, symbols, binary, control codes, and image data (DENSO WAVE INCORPORATED., 2003) (KEYENCE CORPORATION., 2005). Since QR Code was developed in Japan, it has the ability to encode JIS Level 1 and Level 2 Kanji character set. One full-width Kana or Kanji character can be efficiently encoded in 13 bits, which allows QR Code to contain 20% more data than other 2D symbologies. An example of QR Code that contains Japanese Kana and Kanji is presented in Figure 22. The maximum data capacity and data translation ratio is presented in Table 4.



The data encoded:
Kana or Kanji character can be efficiently encoded by using QR Code

An example of QR Code that contains Kana and Kanji

Figure 22: An example of QR Code that contains Kana and Kanji

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003). Retrieved October, 7, 2005, from http://www.denso-wave.com/qrcode/qrgene4-e.html

Table 4: QR Code Maximum Data Capacity and Data Translation Ratio

QR Code Maximum Data Capacity and Data Translation Ratio		
Maximum Data Capacity	Numeric only	Max. 7,089 characters
	Alphanumeric	Max. 4,296 characters
	Binary (8 bits)	Max. 2,953 bytes
	Kanji, full-width Kana	Max. 1,817 characters
Data Translation Ratio (The number of cells to encode a character)	Numeric only	3.3 cells/character
	Alphanumeric	5.5 cells/character
	Binary (8 bits)	8 cells/character
	Kanji, full-width Kana	13 cells/character

Source: Understanding 2D Symbologies: Detailed Information on Barcodes (Japan Automatic Identification Systems Association, 2004), Tokyo: Ohms

3.1.3 Advantageous Features

I. Colour reversal and round cells

QR Code has colour reversal function. That is, cells in QR Code symbols can be printed light-on-dark or dark-on-light (Japan Automatic Identification Systems Association, 2004) In addition, QR Code can encode and decode round cells (Japan Automatic Identification Systems Association., 2004). This feature is especially advantageous for direct part marking since 2D codes may be marked on the materials that are not always light colour. In case of laser marking technique is used, cells may appear round (Japan Automatic Identification Systems Association., 2004) (see, Figure 23- ⅰ).

II. Masking

QR Code masking is a technique used for easy and quick reading of the code. Masking makes finder patterns invisible. It is also used to allocate the black and white dots evenly to avoid the code misreading. There are 8 mask patterns and the best pattern is selected as a result of evaluation of each pattern (Japan Automatic Identification Systems Association, 2004) (see, Figure 23- ⅱ).

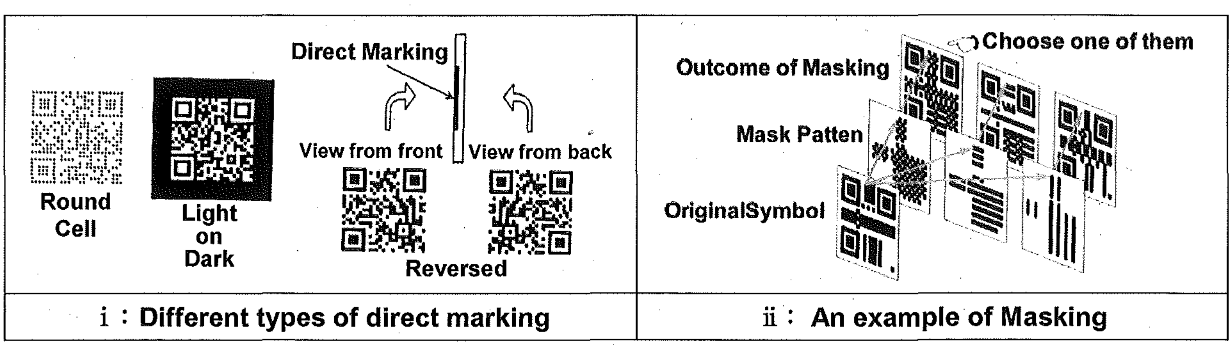


Figure 23: Masking Operation and Direct Marking Examples

Source: Understanding 2D Symbologies: Detailed Information on Barcodes (Japan Automatic Identification Systems Association, 2004), Tokyo: Ohms

III. Strong resistance against distortion, dirt, and damage

Alignment patterns allow QR Code to be resistant against distortion. As previously explained, it also has error correction capability. A maximum 30% of codewords can be restored (DENSO WAVE INCORPORATED., 2003) (KEYENCE CORPORATION., 2005). Examples of damaged QR Codes are presented in Figure 24.

Distorted code	Dirty code	Torn code

Figure 24: Examples of damaged QR Codes

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003). Retrieved October, 7, 2005, from http://www.denso-wave.com/qrcode/qrgene4-e.html

VI. Structured append

When QR Code cannot be placed in available space, it can be divided into multiple data areas and vice versa. That is, information stored in multiple QR Code symbols can be reconstructed as single data symbols. One data symbol can be divided into up to 16 symbols, allowing printing in a narrow area. The Figure below shows an example of structured append function (see, Figure 25, p.51).

Figure 25: An example of QR Code Structured Append

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003). Retrieved October, 7, 2005, from http://www.denso-wave.com/qrcode/qrgene4-e.html

3.1.4 Scanning and decoding

As previously mentioned, Charge Coupled Device (CCD) scanners are used for capturing the 2D symbol image. The structure of CCD imager for 2D-barcode is presented in Figure 11 (p.19). A built-in CCD camera of mobile phones operates in the same way although there might be difference in quality of functions. Figure 26 shows the decoding process of QR Code.

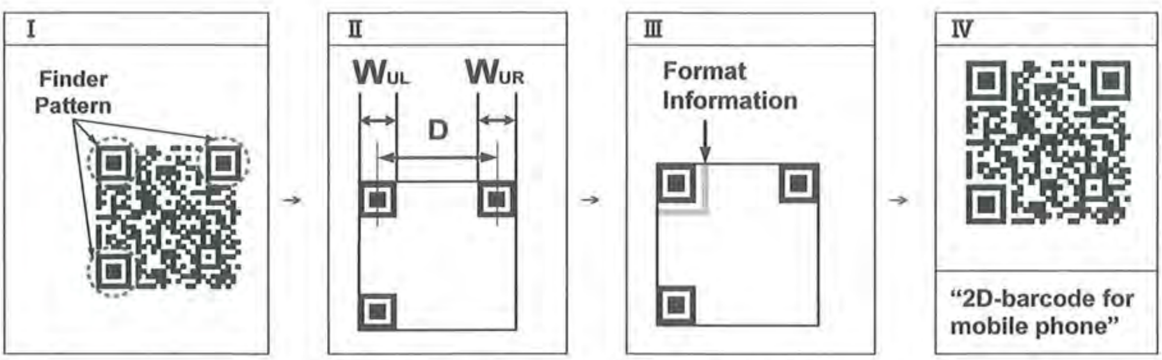


Figure 26: Decoding Process of QR Code

Source: QR Code.com. (DENSO WAVE INCORPORATED., 2003). Retrieved October, 7, 2005, from http://www.denso-wave.com/qrcode/qrgene4-e.html

Once the code image is captured:

I. Three finder patterns are located and the centre of each pattern is calculated (Figure 26-Ⅰ).

II. Determine the module size of the symbol by measuring the W_{UL} and W_{UR} and also determine the symbol size by calculating the size of **D** (Figure 26-Ⅱ).

III. Decode the format information and define the error correction level and masking pattern used (Figure 26-Ⅲ).

IV. Firstly, detect the whole data and then remove the codewords for error correction. Decode the raw data according to the defined method such as the error correction level and the masking pattern. As a result of decoding, **"2D-barcode for mobile phone"** has appeared (Figure 26-Ⅳ).

3.1.5 Applications

I. Industry usage

QR Code has been utilized in a variety of applications. Examples are order/product scanning system for automotive parts, process control system for electronic circuit boards, logistics control system for food products, shipping control system for garment products, sales Management system for contact lenses, and sales management system for glasses.

II. Camera phone application

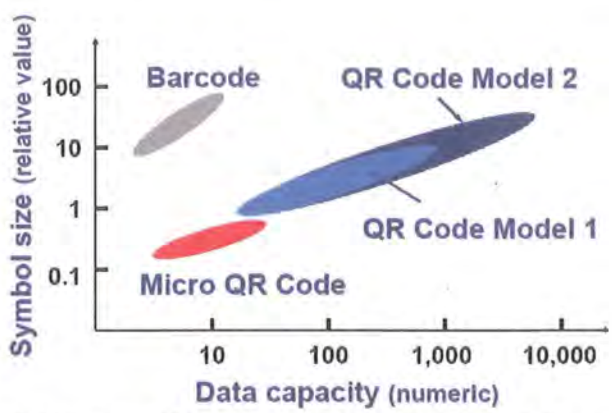
Examples of camera phone applications are business card, on-line booking, and ring tones for mobile phones. In recent years, ID stamp/sticker has also been widely used (see, Figure 27).

Figure 27: Examples of QR Code application

Source: QR Code Stamp.com (Home Computing Network., n.d.). Retrieved September 3, 2005, from http://www.qrcode-stamp.com/

3.1.6 Micro QR Code

Micro QR Code is a small-sized QR Code that fits applications where a smaller space and smaller amount of data are required. ID of printed circuit boards and electronics parts are examples of the Micro QR Code usage. The efficiency of data encoding has been increased with the use of only one position detection pattern. Figure 28 shows the relationship between data capacity and code size in different codes.



※ The size of Version 1 QR Code is assumed as 1.

Figure 28: The relationship between data capacity and code size in different codes

Source: New Work Item Proposal Micro QR Code. Inclusion to ISO/IEC 18004 QR Code (ISO/IEC SC 31 National Body of Japan, 2003). Retrieved October 13, 2005, from http://isotc.iso.org/

A major feature of Micro QR Code is it has only one position detection pattern, compared with regular QR Code that requires position detection patterns at the three corners of a symbol.

Furthermore, Micro QR Code requires only a two-module wide margin around a symbol, whereas at least a four-module wide margin is required for QR Code. This configuration of Micro QR Code enables the code to be printed in areas where QR Code cannot be placed due to its symbol size.

One drawback of Micro QR Code is its data capacity. The maximum data capacity of Micro QR Code is 35 characters (numeric), or 21(alphanumeric), or 15 (binary=8-bit), or 9 (Kanji) (DENSO WAVE INCORPORATED., 2003). Accordingly, the use of Micro QR Code in the mobile phone application is considered to be impractical. Hence, it seems reasonable that further investigation of Micro QR Code should be out of scope in this study.

Note: QR Code and Micro QR Code were consulted for full information provided by DENSO WAVE INCORPORATED (2003), unless otherwise indicated.

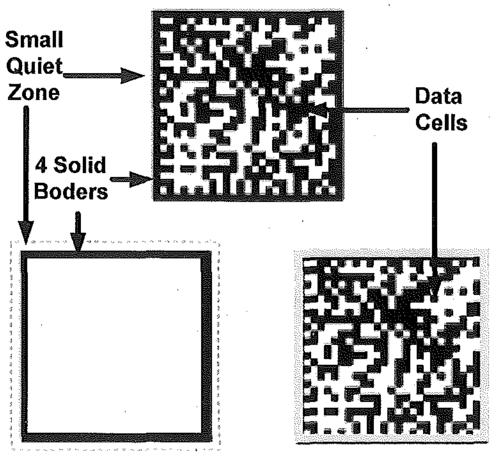
3.2 Veri Code

The main features of VeriCode®, which is related to the use of camera phones, are its scalability in size to fit available space being shaped either rectangular or square and the ability to omni-directionally detect the code regardless of the shape (VERITEC, Inc, n.d.). The skewed codes up to a 60% angle off the horizontal plane can be successfully read. The amount of information within the VeriCode® symbol is user selectable, which determine the density of the code and thus solve the resolution problem of camera phones. VeriCode® also contains high percentage of error detection and correction (EDAC) ability (15%-25%) ensuring valid information. Its custom design capability with unique encryption techniques allows the symbol to provide additional security. The ability of directly marking on most materials, including metal, glass and plastic is also the strength of VeriCode®. VSCode®, which is a derivation of VeriCode®, has capacity of over 4,000 bytes (VERITEC, Inc, n.d.).

A unique feature of VeriCode® is its capability of storing biometric data and thus, is used in access control applications.

Note: VeriCode® and VSCode® were consulted for full information provided by VERITEC, Inc. (n.d.), unless otherwise indicated.

3.2.1 Veri code Symbol Structure



Any VeriCode®, VSCode® comprises the following major components:

- A solid border frame (4 solid boders)
- The internal data field within the data frame.
- Quiet zone (an invisible border surrounding the data field)

Figure 29: Symbol Structure of VeriCode® and VSCode®

Source: Benefits of Veritec's 2D Codes - VeriCode® and VSCode®. (VERITEC, Inc., n.d.). Retreived May 05, 2005, http://www.veritecinc.com/vericode.html

Figure 29 shows the symbol structure of VeriCode® and VSCode®. VeriCode® and VSCode® consist of a solid border frame, data field, and an invisible border called "quiet zone" (VERITEC, Inc., n.d.). A solid border frame serves as the outside border of a data matrix field. Within this data frame is the internal data field that is comprised of single cell units representing binary data (VERITEC, Inc., n.d.). The quiet zone border requires the width of at least one data cell. The quiet zone is critical to separating the data field from surrounding noises (VERITEC, Inc., n.d.).

3.2.2 VSCode®

VSCode® symbols are capable of storing more than 4,000 bytes of information in a single symbol. Because of its high data capacity, VSCode® can be used as a secure container as well as a portable data storage unit (VERITEC, Inc., n.d.). This portable data storage capability is ideal for storing personal, financial and/or biometric data information. The data stored within the VSCode® can be instantly obtained without accessing a central database and can be securely protected with an individualized biometric key.

VSCode® symbol shares many features with the VeriCode® except that VSCode® has much larger data capacity. The VSCode® stores up to 4,151 bytes of data, whereas the maximum data capacity of VeriCode® is 500 bytes. This is the biggest capacity 2D-barcode. Therefore, description about VeriCode® represents both VeriCode® and VSCode®.

3.2.3 Symbol Description

I. Error Correction

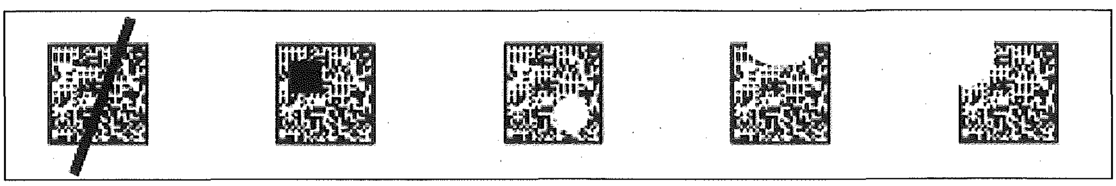


Figure 30: Examples of Damaged Symbols

Source: Benefits of Veritec's 2D Codes - VeriCode® and VSCode®. (VERITEC, Inc., n.d.). Retreived May 05, 2005, http://www.veritecinc.com/vericode.html

VeriCode® contains high percentage of Error Detection And Correction (EDAC) capability ranging from 15% to 25%, which ensures valid information upon decoding. It enable the encoded data to be 100 % restored even if up to 35% of the symbol becomes damaged or is missing. Examples of damaged symbols are shown in Figure 30. The feature not only determines if an error is present in the code, but also assures that the correct information is recovered during the decoding process. Accordingly, VeriCode® symbol can maintain its integrity and give no false data. That is, VeriCode® either delivers accurate information or no information. The error correction is implemented by adding Reed-Solomon code to the original data.

II. Symbol shapes

VeriCode® symbols can be square or rectangular in shape. Examples are shown in Figure 31. Both symbols in Figure 31 contain the same amount of data.

Symbol size – 21×21 cells	Symbol size – 12×30 cells
Information contained: 31 Alphanumerics	Information contained: 31 Alphanumerics
abcdefghijklmnopqrstuvwxyz12345	abcdefghijklmnopqrstuvwxyz12345

Figure 31: VeriCode® Symbol Shapes

Source: Benefits of Veritec's 2D Codes - VeriCode® and VSCode®. (VERITEC, Inc., n.d.). Retreived May 05, 2005, http://www.veritecinc.com/vericode.html

III. Symbol size

The size of the VeriCode® is variable. VeriCode® is also scaleable in size to fit available space. Therefore, data density is not a function of the size of the code. Users can select the size of code based upon space requirements and not on the amount of data that needs to be encoded.

IV. Encodable character set

Any language or character sets can be encoded into the VeriCode®. That is, VeriCode®

is capable of containing any information that can be converted into a stream of binary data. The symbol can be used as a standalone data field or key to a database file.

V. Skew Resistant

The skew versatility of VeriCode® allows the code to be captured and decoded at up to a 60% angle off the horizontal plane. This permits a range of flexibility while still maintaining data accuracy.

VI. 360-degree orientation

VeriCode® can be read in any orientation or skew and no manual positioning of the code is necessary. The omni-directional feature allows the symbol to be used for applications where the orientation of the symbol may appear randomly (e.g. parts during automated assembly processes). The symbols shown in Figure 32 can be accurately read.

Figure 32: Examples of the VeriCode® symbols placed with random orientation

Source: Benefits of Veritec's 2D Codes - VeriCode® and VSCode®. (VERITEC, Inc., n.d.). Retreived May 05, 2005, http://www.veritecinc.com/vericode.html

3.2.4 Advantageous Features

I. Marking capability

The VeriCode® symbol can be encoded and marked on approximately 98% of all materials. There are over 35 different methods of marking the VeriCode® symbol. Examples are provided in Table 5.

Table 5: VeriCode® Marking Method

Marking Method	Description
Thermal printers	It produces labels on heat sensitive paper.
Laser Etching	This is the most versatile method of marking the VeriCode®.
The dot-peen	It directly marks by creating small indentation on the material surface.
Micro abrasive blasting	This is a non-contact process that uses fine abrasive particles to pelt through a fine stream of air through a small nozzle tip to engrave the VeriCode® symbol directly onto the material surface.

II. Integration with the other automatic identification technology

VeriCode® can be used with or within electronic media such as RFID, or Smart Chip for data storage and access. It often enhances the security of applications where such technique is used (see, Figure 33).

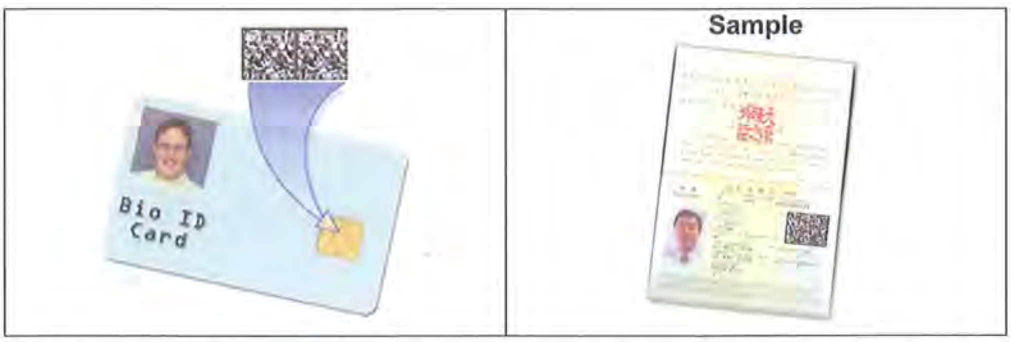


Figure 33: Examples of VeriCode® with Smart Card Media and VeriCode® in Passport

Source: Benefits of Veritec's 2D Codes - VeriCode® and VSCode®. (VERITEC, Inc., n.d.). Retreived May 05, 2005, http://www.veritecinc.com/vericode.html

III. Data Encryption

Unique encryption technique together with custom design capability allows VeriCode® to provide additional security. The encrypted data are incorporated within the code.

IV. Biometric Data

One of the distinctive features of VeriCode® is that it can store biometric data. With the high data capacity of over 4,000 bytes of data, VSCode® is capable of storing biometric data, which often require great data capacity. The symbol also can be secured by using security technique such as data encryption. Unlike RFID and Smart Card technologies, information within the code cannot be changed, once the data is encoded and a VSCode® is generated and printed on an ID card. A new card should be issued to change the information. In addition, the code can be inspected visually for signs of tampering and damage.

3.2.5 Scanning and decoding

VeriCode® symbol can be scanned and decoded using CCD camera vision technology. The CCD camera vision technology can decode VeriCode® instantly.

3.2.6 Applications

I. Industry Usage

VeriCode® and VSCode® are utilized in applications that require high data density in a small or limited space, great data capacity, and ability of encoding secured data.

Examples are ID cards that utilize biometric identification, automated manufacturing that must deal with small items/products, and consumer products such as library systems and catalogue industry (see, Figure 34- i).

II. The mobile phone applications that utilize VeriCode® and VSCode®

With VeriCode® and/or VSCode®, the mobile phone serves the function of an electronic credit card or ID card. With the electronic media, information such as credit card details, bank account, airline tickets, bus tickets, and medical information can be transmitted to the individual mobile phone. For example, if a concert ticket is purchased, the ticket will be sent to the mobile phone of the customer in the form of VeriCode®. As it can be used in the same way as an ordinary ticket is used, the customer is required to show the symbol at the entrance of the concert hall. Once the code is decoded and the validity of the ticket is checked, the customer is allowed to enter the hall. With the use of VeriCode®, this new type of mobile phone application protect privacy, prevent fraud, and provide a secure and quick way to handle daily transaction. Figure 34- ii shows an example of VeriCode® use in camera phone application.

	
i : **VeriCode® used in the library system**	ii : **VeriCode® utilized in mobile application**

Figure 34: Applications that utilizes VeriCode® and/or VSCode®

Source: Benefits of Veritec's 2D Codes - VeriCode® and VSCode®. (VERITEC, Inc., n.d.). Retreived May 05, 2005, http://www.veritecinc.com/vericode.html

3.3 Semacode (Data Matrix)

Semacode has adapted the public domain standard Data Matrix 2D-barcode format to encode plain-text Uniform Resource Locators (URLs) (Semacode.org., n.d.). Data matrix is a robust code that can store hundred of characters (a maximum theoretical density of 500 million characters to the inch) (Barnes, Bradshaw, Day, Schott, & Wilson, 1999), recovering up to 38.9 % of lost data due to damage (Japan Automatic Identification Systems Association., 2004). By using camera phones that support Semacode, URL will be automatically read out of the code and presented. Lightning condition and the distance from camera to the target is important for reading the code properly. The best result can be obtained under evenly lit, bright, and high contrast condition (Semacode.org., n.d.) although it is believed that Data Matrix codes can be read under widely varying lighting conditions under very low contrast (RVSI Acuity CiMatrix., n.d.). This may attribute to the quality of cameras equipped with mobile phones. Camera phones with less than VGA resolution (640 × 480 pixels) and/or without a floating point unit cannot process the Semacode properly (Semacode.org., n.d.). A phone should be placed around 10-15 cm away from the target code in order to read it precisely (Semacode.org., n.d.). Most mobile phone manufacturers such as Nokia, Sony Ericsson, Sharp, and Motorola support Semacode.

Semacode is simply a logical layer (an application layer) on top of the standardized Data Matrix code. Hence, the characteristics of Data Matrix apply the same to semacode, with the restriction that the content may only be a URL as defined by W3C (S. Woodside, personal communication, July 15, 2005). In the following section, therefore, detailed information of Data Matrix code is provided.

3.3.1 Data Matrix

Data Matrix is a two-dimensional matrix symbology invented by International Data Matrix, Incorporated in 1987 (LaMoreaux, 1995). A two-dimensional imaging device such as a CCD camera is necessary to scan the symbology. Data Matrix is designed with a fixed level of error correction capability. It supports industry standard escape sequences to define international code pages and special encodation schemes. Data Matrix is used for small item marking applications using a wide variety of printing and marking technologies (AIM, Inc., n.d.).

Data Matrix format is adopted for semacode utilization for the following reasons; the code is:

I. capable of encoding more than 100 ASCII characters;

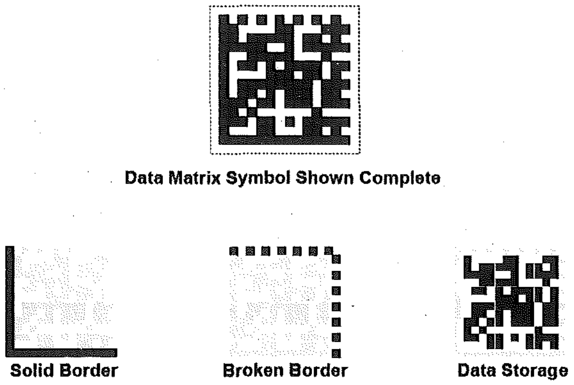
II. popular to ensure a diverse toolset exists;

III. visually neutral; and

IV. an open standard. (Semacode.org., n.d.).

3.3.2 Data Matrix Symbol Structure

The symbol contains dark and light square data modules. It has a finder pattern of two solid lines and two alternating dark and light lines on the perimeter of the symbol, which is surrounded on all four sides by a quiet zone border (RVSI Acuity CiMatrix., n.d.) (see, Figure 35, p.65).



Any Data Matrix symbol comprises the following major components:

- The L-shaped solid border (Finder pattern)
- The broken border on the opposite corner
- The data storage area inside the symbol (Finder pattern)
- The quite zone outside of the symbol (Minimum size of the quiet zone is equivalent to the size of one cell)

Figure 35: Data Matrix Symbol Structure

Source: Data Matrix Basics (RVSI Acuity CiMatrix., n.d.). Retrieved October 01, 2005, from, http://www.cimatrix.com/DM%20Symbol%20Construction.html

The L-shaped solid borders are used primarily to define physical size, orientation, and symbol distortion, whereas the broken borders on the opposite corner are basically used to define the cell structure of the symbol. The latter also assists in determining physical size and distortion of the symbol (LaMoreaux, 1995).

3.3.3 Symbol Description

I. Error Correction

Data Matrix symbols use two types of error correction algorithms: convolutional-code error-correction algorithm and Read-Solomon error-correction algorithm. Whereas Error Checking and Correcting (ECC) level 200, which is in common use at present use Read-Solomon error-correction algorithm, ECC level 000 to 140 (5 levels ranging from ECC-000, ECC-050, ECC-080, ECC-100, to ECC-140) use convolutional-code error-correction (LaMoreaux, 1995). ECC level 200 was developed by Data Matrix Incorporated in 1995 to improve the data capacity of Data Matrix symbol and also to remedy the shortcoming of ECC 000 to ECC-140 (Japan Automatic Identification Systems Association., 2004). The error correction level of ECC-200 is determined in accordance with the symbol size (i.e. users cannot select the error correction level) as opposed to ECC 000 to ECC-140 whose error correction levels can be chosen as required by certain application. ECC Level 200 is utilized in semacode. Therefore, the information on ECC-200 will be provided hereafter.

The detailed information on ECC-200 symbols such as symbol size, maximum data capacity, error correction ratio is presented in Table 28 (for square symbols) and 29 (for rectangular symbols) in Appendix 4 (p.165).

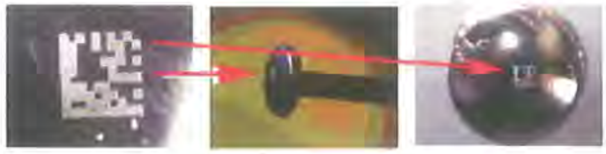
Table 6: ECC-200 Minimum and Maximum Data Capacity

	Minimum Data Capacity			Maximum Data Capacity		
	Size	Data Capacity		Size	Data Capacity	
ECC-200	10×10	Numeric	6	144×144	Numeric	3116
		Alphanumeric	3		Alphanumeric	2335
		8bit Byte	1 byte		8bit Byte	1556 byte

Source: Understanding 2D Symbologies: Detailed Information on Barcodes. (Japan Automatic Identification Systems Association, 2004). Tokyo: Ohmsha

Data Matrix ECC-200 symbols have an even number of modules on each side (Barnes, Bradshaw, Day, Schott, & Wilson, 1999). As indicated in Table 6, the minimum data capacity of an ECC-200 symbol is 6 numeric digits, 3 alphanumeric characters, or 1 byte in a symbol 10 modules square, whereas maximum data capacity is 3116 numeric digits, 2335 alphanumeric characters, or 1556 byte in a symbol 144 modules square. That is, the symbol is scalable between 1mm^2 to a 14 inch^2 (Barnes, et al, 1999). Figure 36 demonstrates that a 12 × 12 Data Matrix code encoding a 6-character string is laser marked on an electronic component measuring only 0.3mm × 0.3mm (0.012" × 0.012"). The component is placed on the letter C of the business card to provide a sense of scale.

The code is placed on the letter C of the word Acuity on a business card.



Data Matrix Symbol on the head of a straight pin

Figure 36: Examples of very small Data matrix codes

Source: Data Matrix Basics (RVSI Acuity CiMatrix., n.d.). Retrieved October 01, 2005, from, http://www.cimatrix.com/DM%20Symbol%20Construction.html

II. Symbol shapes

Data Matrix symbols can be either square or rectangular (see, Figure 37). Both symbols in Figure 37 contain the same amount of data.

Symbol size – 20×20 cells	Symbol size – 12×36 cells
Information contained: 31 Alphanumerics	Information contained: 31 Alphanumerics
abcdefghijklmnopqrstuvwxyz12345	abcdefghijklmnopqrstuvwxyz12345

Figure 37: Data Matrix Symbol Shapes

Source: Data Matrix Basics (RVSI Acuity CiMatrix., n.d.). Retrieved October 01, 2005, from, http://www.cimatrix.com/DM%20Symbol%20Construction.html

III. Symbol size

The maximum size of each block is 24 × 24, which is to prevent symbols from being distorted. Hence, a symbol is divided into blocks as required. For example, a symbol that contain more than 24 × 24 cells is divided into 4 blocks (see, Figure 38, p.68). The symbol in Figure 38- i contain 62 alphanumeric characters, whereas the symbol in Figure 38- ii encode 63 alphanumeric characters. As the latter contain more than 24 × 24 cells, the symbol is divided into 4 blocks.

1 block: Symbol size – 24×24 cells	4 blocks: Symbol size – 26×26 cells (= more than 24×24 cells)
i : Information contained: 62 Alphanumerics	ii : Information contained: 63 Alphanumerics
1234567890 Abcdefghijklmnopqrstuvwxyz ABCDEFGHIJKLMNOPQRSTUVWXYZ	1234567890 Abcdefghijklmnopqrstuvwxyz ABCDEFGHIJKLMNOPQRSTUVWXYZ+**A**

Figure 38: Data Matrix Symbol Size

IV. Encodable character set

Two types of character set can be encoded in Data Matrix symbols: 128 characters conforming to ISO 646 and user-defined extended character set of 256 characters.

3.3.4 Advantageous Features

Other features worthy of special mention are provided below.

I. Colour reversal

Cells in Data Matrix symbols can be printed light-on-dark or dark-on-light (Eley, 2000) (Japan Automatic Identification Systems Association., 2004). This feature is especially advantageous for direct part marking since 2D codes may be marked on the materials that are not always light colour (Japan Automatic Identification Systems Association., 2004) (see, Figure 39, p.69).

Dark on light Symbol		Light on dark Symbol	
	Information contained: 26 Alphanumerics		Information contained: 26 Alphanumerics
	abcdefghijklmnopqrstuvwxyz		abcdefghijklmnopqrstuvwxyz

Figure 39: Dark on light and light on dark symbols

Source: Data Matrix Basics (RVSI Acuity CiMatrix., n.d.). Retrieved October 01, 2005, from, http://www.cimatrix.com/DM%20Symbol%20Construction.html

II. Data compaction

These schemes are defined to compact a number of data characters more densely than at 8 bits per character (LaMoreaux, 1995).

III. Code pages

This mechanism enables characters from other parts of ISO 8859 (e.g. Arabic, Cyrillic, Greek, Hebrew) and other data interpretations or industry-specific requirements to be encoded. Many different code pages are specified with a potential capacity of 256 (LaMoreaux, 1995).

IV. Structured append

This feature allows a large amount of data to be represented logically and continuously in up to 16 Data Matrix symbols. The original data can be correctly reconstructed regardless of the order of the symbols scanned (LaMoreaux, 1995). 3 additional bytes are required for this function to work (IDAutomation.com, Inc., 2004). The first 4 bits of the first byte identify the position of the particular symbol in the sequence. The last 4 bits identify the total number of symbols in the sequence. The second byte and third byte that are used as a file identifier have a value between 1 and 254 (up to $254 \times 254 =$

64516 identifiers) (IDAutomation.com, Inc., 2004).

3.3.5 Scanning and decoding

I. Scanning

The code is read by CCD video camera or CCD scanner.

II. Symbol reading

The code can be read:

i. omni-directionally

ii. with only a 20 percent contrast ratio.

iii. at distances ranging from contact to 36 inches (91.44 cm) away

iv. in the ratio of 5 symbols per second. (Source, Barnes, et al, 1999).

Figure 40 (p.71) shows advantageous reading features of data matrix symbols.

A Data Matrix code can be read omni-directionally.	A Data Matrix code can be read under widely varying lighting conditions under very low contrast.	A Data Matrix code can be read even if a substantial portion of the mark is missing or obscured.

Figure 40: Advantageous Reading Features of Data Matrix Symbols

Source: Data Matrix Basics (RVSI Acuity CiMatrix., n.d.). Retrieved October 01, 2005, from, http://www.cimatrix.com/DM%20Symbol%20Construction.html

III. Decoding

Two steps take place for a Data Matrix/Semacode symbol to be decoded: i .Image recognition and ii . Decoding. The following is the decoding process for Semacode provided by Semacode organization.

i. Image recognition

Once the image has been captured by the phone's camera subsystem, the reader software:

A. locate the semacode node inside the image

B. correct for image distortion

C. acquire the raw data from the image

Figure 41: Image Recognition

Source: All the technical details you could possibly want, and more. (Semacode.org., n.d.). Retrieved June 13, 2005, from http://semacode.org/about/technical/#intro

A variety of techniques from the field of image recognition should be applied to detect the edges of the symbol, discard objects that are not nodes, and determine the logical geometry of the symbol. Once the image is detected (see, Figure 41), image distortion including some rotation, perspective error, and fuzzy edges must be corrected. In the case of the mobile phone use, these operations are implemented within limited memory and on a relatively slow CPU (Semacode.org., n.d.)

The raw data result is the value of light or dark (i.e. binary 1 or 0) for each module in the symbol, on a 2-dimensional matrix grid (Semacode.org., n.d.).

ii. Decoding

The next phase of the decoding process is to apply Reed-Solomon error correction to the data and decodes the contents. This is done by the reader software. The result of this stage, if successful, is a decoded message, in other words a string of characters.

3.3.6 Applications

I. Industry usage

The most popular applications for Data Matrix are the marking of small parts and small items such as integrated circuits and printed circuit boards for part-number and traceability information (Barnes, et al., 1999) (LaMoreaux, 1995). Data Matrix has been adopted by NASA that intends to use the symbol to identify and track the millions of parts used in the space program. The symbol is imprinted on the thousands of heat-resistant tiles on the Space Shuttle using a traditional marking technique (see, Figure 42). The symbol is also used for high-speed sorting and shipping information. In addition, it is useful for pharmaceutical companies to identify labels.

A 10 × 10 character identification mark approximately 0.3 centimeter on a side imprinted into an aviation-grade aluminum alloy using the Lasershot Marking System.

(Source: Science & Technology Review, Lawrence Livermore National Laboratory Operated by the University of California for the U.S. Department of Energy, 2001, http://www.llnl.gov/str/ September01/ Hackel.html)

Figure 42: An example of direct part markimg

II. Mobile application (as Semacode)

The main application of Semacode is Uniform Resource Locator (URL) retrieval (i.e. implementing physical hyperlinks that allow a mobile phone's browser to load the designated web page). Furthermore, Semacode is utilized in the applications such as business cards, conference badges, and live delivery of urban geographical information (e.g. providing the location of GSP-equipped busses) (Rohs, 2004).

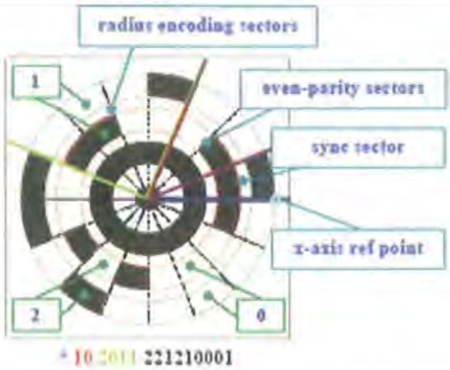
Note: Data Matrix code and Semacode were consulted for full information provided by Semacode.org. (n.d.) and RVSI Acuity CiMatrix. (n.d), respectively, unless otherwise indicated.

3.4 ShotCode (SpotCode)

ShotCode from OP3 (OP3 AB Sweden, 2005) also known as SpotCode, recognizes the rotation of the code tags in the image (Rohs, 2004) and thus, codes are angle-free. ShotCode allows a Bluetooth-enabled camera phones to control active displays as a sophisticated pointing-device regardless of shape and size of computers. The code can also work as a user interface for devices without display or input capability of their own (Madhavapeddy, Scott, Sharp, & Upton, 2004).

3.4.1 ShotCode (SpotCode) Symbol Structure

SpotCode is a derivative of a 2D circular barcode tags or ringcode (also known as TRIP tag or TRIP code). TRIP is short for Target Recognition using Image Processing (Ipiña1, Mendonça2, Hopper, 2002). SpotCode was acquired by a Swedish campany called OP3 (OP3 AB Sweden, 2005) and named ShotCode. In order to address the symbol structure, the original 2D-barcode, namely, the structure of TRIP code is introduced in this section. The symbol structure of TRIP code is provided in Figure 43 (p.75).



TRIP tags comprise the following major components:

Two concentric rings surrounding the bull's-eye of a target. Each ring is divided into 16 sectors:

- 1st sector (= synchronization sector)
- The subsequent two sectors
- The following 4 sectors
- The remaining nine sector

Figure 43: TRIP code (SpotCode) Symbol Structure

Source: TRIP: a Low-Cost Vision-Based Location System for Ubiquitous Computing. (Ipiña1, et al, 2002). Retrieved May, 10, 2005, from, http://citeseer.ist.psu.edu/ ipina02trip.html

TRIP ringcodes (TRIPtags) encode a ternary number in the range 1-19,683 (3^9-1) in the two concentric rings surrounding the bull's-eye of a target. The two rings are divided into 16 sectors.

1st Sector (i.e. synchronization sector) indicates where the TRIP code begins. This sector presents black areas in its section of the encoding rings and thus a configuration is impossible everywhere else in this code. The subsequent two sectors are reserved for undertaking an even parity check on the identifier (TRIPcode) extracted. The following 4 sectors encode the radius of its central bull's-eye in millimetres. Finally, the remaining nine sectors encode a ternary identifier.

3.4.2 Symbol Description

I. Error Detection

An even parity check that is allocated in the 2nd and 3rd sectors is used to detect decoding errors (Scott, Sharp, Madhavapeddy & Upton, 2005).

II. Symbol shape

TRIP tag is based on a circular pattern as it was originally designed for 3D localization of tagged objects in the highly cluttered environments where the central bull's eye of a TRIP tag represents a very distinctive pattern. Circles are less common shapes than right angles, squares and rectangles (Ipiña1, Mendonça2, & Hopper, 2002). In addition, the detection of squares in those cluttered environment supposes an expensive computational task given the many straight edges combinations possible within an image.

III. Symbol Colour

Likewise most currently available 2D-barcodes, black and white pattern are selected in order for TRIP tag to provide a distinctive contrast between the marker and surrounding objects. This ascribes to 3 major factors:

- **i.** to process monochromatic images is computationally cheaper than the colour images;
- **ii.** currently monochromatic printers are more widely available; and
- **iii.** using colour is both difficult and unreliable as the lighting conditions affect great deal reading objects and the colour sensitivity of different CCD devices is not identical (Ipiña1, et al).

IV. Symbol size and Encodable character

TRIP code is a printable and resizable ringcode. It encodes a ternary number in the range 1 – 19,683 (3^9-1) in the two concentric rings surrounding the bull's-eye of a target.

3.4.3 Advantageous Feature

I. 360-degree orientation

The first sector (i.e. synchronization sector is used to specify the orientation of the tag. Therefore, TRIP tag can be read omni-directionally (Ipiña1, Mendonça2, & Hopper, 2002).

3.4.4 Scanning and decoding

Whereas inexpensive CCD cameras such as web-cams or CCTV cameras are utilized in TRIP system, ShotCode uses a built-in CCD camera of mobile phones as image capturing and processing device. There may be difference in quality of devices used between the former system and the latter applications.

In case of the latter, tag reading software should be installed into the mobile phone used to detect and process ShotCode. The software decodes the SpotCode as soon as it appears in the frame of the phone. The code is read in anti-clockwise fashion from the synchronization sector.

3.4.5 Applications

Applications of SpotCode focus on the human-computer interaction, whereas ShotCode is often used for electronic commerce (e-commerce). The followings are examples of applications where SpotCode and ShotCode are utilized, respectively.

I. SpotCode application

World Map application, which is designed for travel agencies, enables users to book flight information (Madhavapeddy, Scott, Sharp, & Upton, 2004). In this application, a user interacts with the plasma screen that shows a map augmented with SpotCodes to book a flight ticket. This is implemented in the same way he use a computer and a mouse. Since a camera phone also has display screen, the relevant information is shown in either the plasma screen or camera phone display.

II. ShotCode applications

ShotCode applications, which are similar to the applications developed for Semacode, include business card, simple game, on-line shopping, trade fair information service, time-registration, logistics and individual communication (OP3 AB Sweden, 2005).

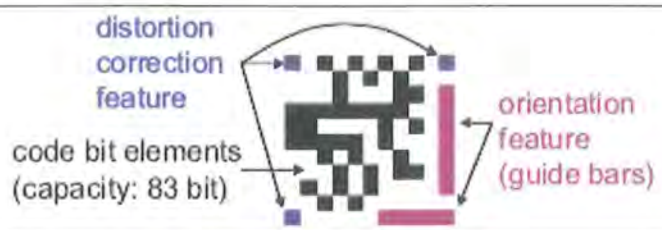
Note: TRIP code and SpotCode were consulted for full information provided by TRIP: a Low-Cost Vision-Based Location System for Ubiquitous Computing (Ipiña1, Mendonça2, & Hopper, 2002) and Using Camera-Phones to Enhance Human-Computer Interaction (Madhavapeddy, Scott, Sharp, & Upton, 2004), unless otherwise indicated.

3.5 Visual Code

The system is developed by Rohs (Rohs, 2005). The feature of Visual Code is its code coordinating system, the visual detection of phone movement, and the determination of the rotation angle and amount of the tiling. Each code introduces a code coordinate system with its origin at the upper left edge of the code and one unit corresponding to a single code bit element (Rohs, 2005). The code coordinate system is independent of the orientation of the code in the image. The code recognition algorithm is able to map points in the image plane to points in the code plane and vice versa.

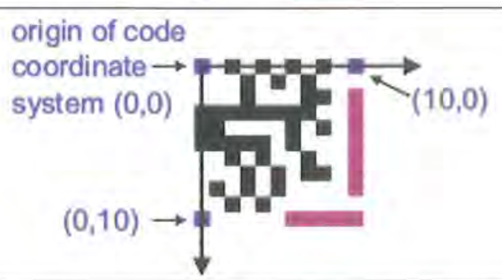
With Visual Codes, areas in printed documents can be linked to online content. Paper documents thus become interactive media.

3.5.1 Visual Code Symbol Structure

<table>
<tr>
<td>


</td>
<td>
Any Visual Code symbol comprises the following major components:

A large and a small guide bar
Three cornerstones
Data area

</td>
</tr>
<tr>
<td>


</td>
<td>
In the code coordinate system,

X-axis extends in horizontal direction to the left and right beyond the code itself
Y-axis extends in vertical direction beyond the top and bottom edges on the code

</td>
</tr>
</table>

Figure 44: Visual Code Symbol Structure and Code Coordinate System

Source: Real-World Interaction with Camera-Phones. (Rohs, 2004). Retrieved March 26, 2005, from http://citeseer.ist.psu.edu/715687.html

As illustrated in Figure 44, Visual Code symbol is composed of combination of larger and smaller guide bars, three corner stones, and the data area with the actual code bits (Rohs, 2004). The bars are used for determining the location and orientation of the code, for detecting the distortion. It is beneficial for detecting even strongly tilted codes. The data capacity in the data area is 83 bits (Rohs, 2004). The 3 cornerstones are designed for the code coordinate system.

As the bottom part of Figure 44 illustrates, each code defines its own local coordinate system with its origin at the upper left edge of the code and one unit corresponding to a single code bit element (Rohs, 2004). Depending on the code size, the mapping between points in the image plane and points in the code plane is more precise than a single coordinate unit. The x-axis extends in horizontal direction to the left and to the right beyond the code itself. Correspondingly, the y-axis extends in vertical direction beyond the top and bottom edges of the code. For each code found in a particular input image, the code recognition algorithm establishes a bijective mapping between arbitrary points in the code plane and corresponding points in the image plane (Rohs, 2004).

3.5.2 Symbol Description

I. Error Checking

Code bits are protected by an (83, 76, 3) linear code that generates an 83-bit codewords from a 76-bit value and has a Hamming distance of 3 in order to detect errors and false orientation features (Rohs, 2004).

II. Symbol shapes and size

Visual Code is square 2D-barcode that consists of black and white square cells.

III. Encodable character set

It is believed that a decimal or hexadecimal number can be encoded into Visual Code.

3.5.3 Advantageous Features

I. 360-degree orientation

The location and orientation of a Visual Code can be identified by the use of guide bars. Thus, the code can be read omni-directionally.

II. Human-computer interaction capability

The code coordinate system, rotation, tilting, and visual movement detection are integrated into the Visual Code system. These features enable applications such as interaction with nearby active displays (Rohs, 2004). The recognition algorithm can accurately maps the coordinates of a targeted point in the code coordinate system. Such operation is independent of the orientation of the camera relative to the code tag (e.g. distance, rotation, and tilting) and also of the camera parameters (e.g. focal point, distance). This allows each point in the viewed image to associate with specific operations. That is, a single Visual Code can be associated with multiple areas, and furthermore, a single image point can be associated with multiple information aspects provided by different rotation and tilting angles.

3.5.4 Scanning and decoding

I. Recognition algorithm※

The followings are main steps performed by the recognition algorithm on the camera image. The resultant is a code information object for each detected code.

i. **Input: image in the camera**

ii. **Output: Set of code information objects that include:**

A. the code value;
B. the image pixel coordinates of the corner stones and guide bars;
C. the rotation angle of the code in the image;
D. the amount of horizontal and vertical tilting※;
E. the distance of the camera to the code;
F. a projective warper object for the code, which implements a planar homography used to transform image coordinates to code coordinates and vice versa;
G. the width and height of the originating image; and
H. a flag indicating the result of error checking.

※The term *tilting* denotes the amount of inclination of the image plane relative to the code plane. *Horizontal tilting* is the amount of inclination of the image plane relative to the horizontal axis of the code. Likewise, *vertical tilting* denotes the amount of inclination of the image plane relative to the vertical axis of the code (Rohs, 2004).

II. Symbol reading

Symbol reading is done by testing the appropriate pixels of the black and white image once position detection of the guide bars and corner stones has been completed, and thus a suitable project mapping has been computed.

※Source: Real-World Interaction with Camera-Phones. (Rohs, 2004). Retrieved March 26, 2005, from http://citeseer.ist.psu.edu/715687.html

3.5.5 Applications

Similar to the SpotCode mobile applications, Visual Code is utilized in applications where human-computer interaction is performed. One of such examples is weather forecast news paper page that contains Visual Codes (See, Figure 45). The 17 regions on the map and all entries in the table are individually mapped to different URLs and thus hyperlinked to specific online content. This enables a user to obtain real-time information about the forecast accessing to the relevant web site through the Visual Code selected. Further, user can see the different aspects of online information by rotating his/her camera phone. In Figure 45, vertical orientation provides information about the snow depth of the chosen area, while the current temperature can be seen by slightly rotating the camera phone.

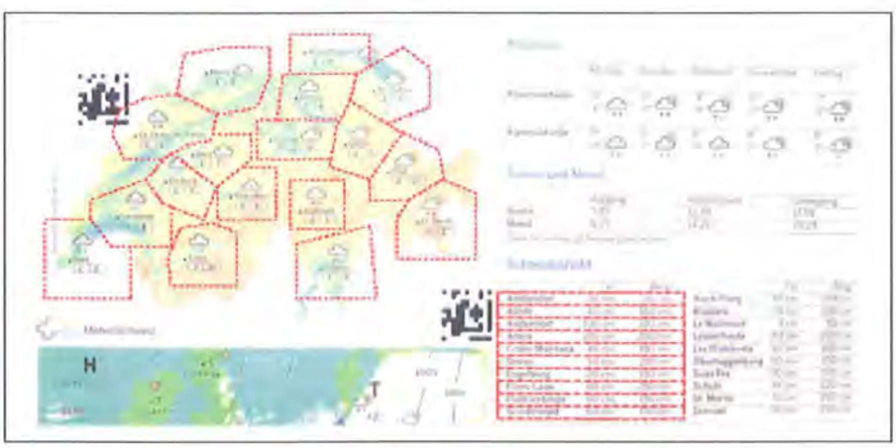


Figure 45: Example of a Weather Forecast Newspaper Page with Visual Codes

Other applications provided Visual Code system include camera-controlled wireframe model of a house, a pong game whose slider can be controlled by tilting the wrist left and right, and a large subway map that is scrolled in response to phone movement. In such applications, camera phones are used as an optical mouse.

3.6 Summary

There are some 2D-barcodes that have been used for camera phone applications: QR Code, VeriCode® (VSCode®), Semacode, Shot Code, and Visual Code. The first 2 2D-barcodes that were originally designed for industrial use has also been used for camera phone applications. Semacode and Shot Code utilized the existing 2D-barcodes for their mobile applications; Data Matrix symbol and SpotCode (TRIP tag) respectively. Visual Code is an original 2D-barcode that is specifically designed for camera phone applications.

Each original 2D-barcode was designed in terms of symbol structure, its capability, advantageous features, and its applications. QR Code is designed for ultra-fast reading using three distinctive finder patterns. Besides camera phone applications, VeriCode® and VSCode® is often used for storing biometric data, making the most of its high data capacity. One of the main features of Data Matrix code is data density. The code can contain more data than any other 2D-barcodes for a given space. All these symbols are scalable in size. In addition, these symbols can be divided into smaller pieces when space is a problem.

In contrast to 2D-barcodes that was originally developed for industrial use, Shot Code and Visual Code have less overall capabilities. Minimum cell size of these 2 symbols is considerably large in comparison with the first 3 symbols. Moreover, these symbols are not scalable in size. Thus, their data capacity is rather limited.

Main camera phone applications of these 2D-barcodes varies, ranging from e-commerce such as on-line shopping, business cards, physical hyperlinks and web page loading, to the realization of active human-computer interaction, such as the controlling of a large-scale wall display.

4 Two Dimensional Barcodes Applications Evolution

4.1 Improvement in Capability

After more than a decade since the first two dimensional (2D) barcode was first introduced in 1988, the 2D-barcode has become a topic of keen research. The focus of early researchers was the capability of 2D-barcodes as a whole in comparison with the traditional one dimensional (1D) barcode, and the effect of their emergence on certain industries and organizations.

I. Taxonomical Research on Two Dimensional Bar Coding

Noting the potential of this new technology, for example, Barnes, Bradshaw, Day, Schott, and Wilson (1999) conducted the thorough taxonomical research on the 2D-barcodes of the time. They first introduced 2D-barcodes in comparison with 1D-barcodes, then analyzed, compared and contrasted the existing 2D-barcodes in terms of their capability (i.e. especially data capacity and accuracy), distinctive features, and applications in which those barcodes had been utilized. Barnes et al. (1999) claim that 1D-barcodes only work as keys to access a database to retrieve the data stored, while 2D-barcodes can be considered to be a portable database.

Barnes, et al. (1999) also refers to the trend of certain industries/organizations towards the standardization in the use of 2D-barcodes at different times. The Automotive Industry Action Group (AIAG), for example, issued a policy for the industry that sets the use of three specific 2D-barcodes in three specific categories as a standard in 1995

(Automatic Identification Manufactures, cited by Barnes, et al, 1999). The recommended 2D-barcodes and relevant categories are Data Matrix in part marking and tracking, PDF 417 for general application, and Maxi Code for freight sorting and tracking (Barnes, et al, 1999). In reference to the study on global markets and applications for 2D-barcode reading equipment and systems completed by Venture Development Corporation, Barnes, et al. claims that PDF 417 and Data Matrix are more likely to become dominant this market globally over a two or three year period due to the prevalence of the former and the rapid growth in adoption of the latter.

As mentioned by Barnes, et al. (1999), 2D-barcodes were initially developed for applications where only a small amount of space was available. Examples are unit-dose packages in the health care industry and electronics assemblies in the electronics industry. The ability to encode a portable database, however, has made 2D-barcodes attractive in applications in which space is not at a premium (Barnes, et al, 1999).

Not only companies/organizations but also academic researchers in a variety of fields, therefore, had their eyes upon the potential of such codes. Some of them have devised new applications, using existing 2D-barcodes. Some have attempted to invent their own new 2D-barcodes and develop applications where such newly invented 2D-barcodes have been utilized. It may be more precise, for most case, to say that they invented the suitable 2D-barcodes to implement the applications originated by them.

II. Predictable Programs in Barcodes

As an example of the former, an interesting attempt was done by Goodloe, McDougall, Gunter, and Alur (2002). Goodloe, et al. (2002) conduct experiments on programming microwave ovens using 2D-barcodes as a mean of delivering verified programs, which demonstrates the feasibility of appliance programming through open application programming interface (API) platforms. In the experiments, the two issues of particular interest for the open APIs on embedded devices are addressed: deliverability and predictability (Goodloe, et al, 2002). While the former concerns the means for getting a program onto an embedded device, the latter requires analysis techniques that make programs predictable.

The high density and mobility of a matrix 2D-barcode, Aztec code in this case, can respond to the demand of the deliverability. That is, it makes it possible to encode and accommodate the program data into a limited space and also deliver the encoded data as an Aztec code onto an embedded device. In contrast, a 2D-barcode was not suitable for the second purpose since it has no mechanism to analyze and correct data content although most of 2D-barcodes are capable of correcting physical errors such as spots or voids. In addition, it is difficult to check the content of the program once it is encoded in the form of a 2D-barcode. In order to cover the second issue, namely predictability, therefore, a formal verification tool called Spin is adapted in this application. The main contribution of their paper is that it demonstrates the feasibility of delivering verified programs in 2D-barcodes, opening the door for open API to control myriad of devices ranging from home appliance to medical devices. However, as Goodloe, et al. themselves point out, no network connectivity is considered in the provided application.

III. A system for a new two dimensional code: Secure 2D code

Secure 2D code proposed by Yeh and Chen (1998) is an example of 2D-barcode invention by researchers. With the discovery that there was no existing 2D-barcodes that provided sufficient security, their focus is to increase security and error correction ability of the 2D-barcode. In addition, Yeh and Chen (1998) propose pattern generation/reading system, which enables any kind of data to be encoded, pre-processing (e.g. compression, encryption, etc) them before encoding. The data ranges from different types of characters (e.g. Chinese characters as well as English), to images, voices, and graphics.

To enhance security, a new data-hiding technique called data disguising is also introduced (Yeh and Chen, 1998). In this technique, the data is divided into two types: general and secret. The general data is first encoded into a 2D code, and then secret data is embedded into the 2D code where the general data have already been encoded. As a result, it becomes a Secure 2D code. Furthermore, 2D-barcodes originally do not have redundancy in contrast to their 1D counterpart, although they are often exposed in an open environment where many types of physical damages (e.g. void, scratch) may occur. In order to ensure the reliability of the code in such environments, Reed-Solomon error correction code is applied to the system. Reed-Solomon code also plays an important role to hide secret data within the encoded contents. Although the system can provide high layered security, accordingly, some error correction capability may be sacrificed in the proposed system (Yeh and Chen, 1998).

The three main topics, namely security, error correction, and pattern generator/ reader are addressed in their study. Secure 2D code emphasizes the security as the name depicts, and the system can be especially useful in the applications that need to encode confidential data such as ID/business card, passport, and driver's license. Similar to the application devised by Goodloe, et al., no network accessibility is considered for applications where Secure 2D code can be utilized.

IV. INTACTA.CODE™

There is another 2D-barcode that put emphasis on the secureness of the code called INTACTA.CODE™ (INTACTA Technologies, Inc, 2002), which was originally developed by INTACTA Labs Limited in Israel (FIJITSU, n.d.) for the defense industry to secure transmission of field battle plans. The name INTACTA is coined from "intact" and the code literally offers secure e-commerce that incorporates all forms of business transactions ranging from paper to digital, digital to paper, and digital to digital based on the notion that we are not living in a totally digital world. That is, many documents still start from paper sources and many ends in the same (INTACTA Technologies, Inc, 2002). Similar to the Secure 2D code, INTACTA.CODE™ uses a variety of techniques (e.g. compression, encryption, error correction, and encoding engines) for ensuring the secure information transfer.

INTACTA.CODE™ is designed on the basis of the idea that the connectivity is all around the world in the modern societies and it is a must that end-to-end security solutions across disparate systems should be provided throughout the data transmission processes to ensure integrity of the format and the content of data. The code provides interoperability between paper and digital systems taking it for granted that the almost seamless connectivity exists throughout the world. That is, code can transfer beyond the border between the physical world and the digital world. However, INTACTA.CODE™ was not developed to establish the connectivity as an interface (i.e. a visual tag) between the real world and virtual world.

4.2 Realization of Ubiquitous Computing

In contrast to the researchers in earlier time, the recent researchers and inventers of 2D-barcodes are more likely to explore the possibilities of the use of 2D-barcodes to establish network connectivity and/or to develop applications that can be utilized along with the networks established by either wire-lined or wireless communication devices, or both. These researchers attempt to use 2D-barcodes as a mean to achieve a world of ubiquitous computing where people use computers in the natural human environment without realizing their presence due to the naturalness of their existence. It is the world that the human-to-human interaction has more priority and attention than human-to-computer interaction (Weiser, 1991). In such a world, human beings are not dependent on the computers. Rather, computers are the ones that readily work for humans to make their life convenient, while the computers invisibly, synchronizing themselves into the background (Weiser, 1991).

These approaches are roughly classified into two categories in terms of their final goals: the accomplishment of Augmented Reality (AR) and the realization of human interaction with computing world. The representatives that are invented to achieve the former are CyberCode and TRIP code, whereas the latter has been addressed by the use of existing codes such as Semacode and SpotCode as well as newly invented 2D-barcode (i.e. Visual Code)

4.2.1 Augmented Reality.

Edinburgh Online Graphics Dictionary defines the term Augmented Reality as follows:

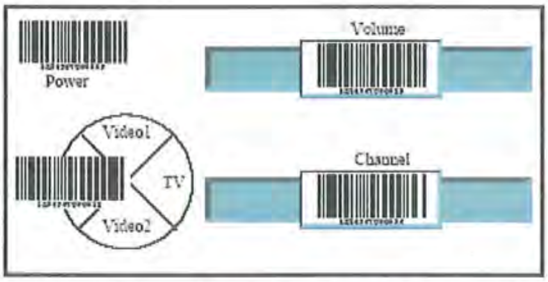
> The idea that an observer's experience of an environment can be augmented with computer generated information. Usually this refers to a system in which computer graphics are overlaid onto a live video picture or projected onto a transparent screen as in a head-up display (Fisher, 1999).

The notion of virtual reality, which attempts to build a world inside the computer, is considered to be most diametrically opposed to the vision of ubiquitous computing world (Weiser, 1991). Accordingly, AR can be seen the opposite to the notion of ubiquitous computing from the viewpoint that sees augmented reality as an environment that includes virtual reality elements as well as real world ones. To make the ubiquitous computing world a reality, however, it is essential to implement a tagging identification (ID) system that establishes a link between physical and digital spaces, an issue which is often addressed in designing augmented reality systems (Rekimoto & Ayatsuka, 2000). Hence, augmented reality can be regarded as a mean to incarnate the ubiquitous computing, and barcodes are used as one type of IDs being tagged in the mechanisms developed for augmented reality systems.

I. FieldMouse (with 1D-barcode)

A FieldMouse invented by Siio, Masui, and Fukuchi (1999) is an early example of an investigation of tagging ID system with the integration of barcode technology and motion detection devices such as an optic mouse. A FieldMouse is either a pen-type mechanical mouse or a gyro-mouse that is integrated with a pen-shaped barcode scanner (Siio, et al, 1999). In this system, the traditional 1D-barcode is used as an ID tag. Once the ID on paper or any other flat surface is detected by the scanner, absolute locations can be calculated by the movement of the mouse based on the location of the ID. FieldMouse is shown in Figure 46- i . The paper remote-controller presented in Figure 46 - ii is an example of FieldMouse applications.

i : **FieldMouse#1: Combination of a barcode reader and a pen-mouse.**



ii : **A paper remote-controller with paper-GUI widgets.**

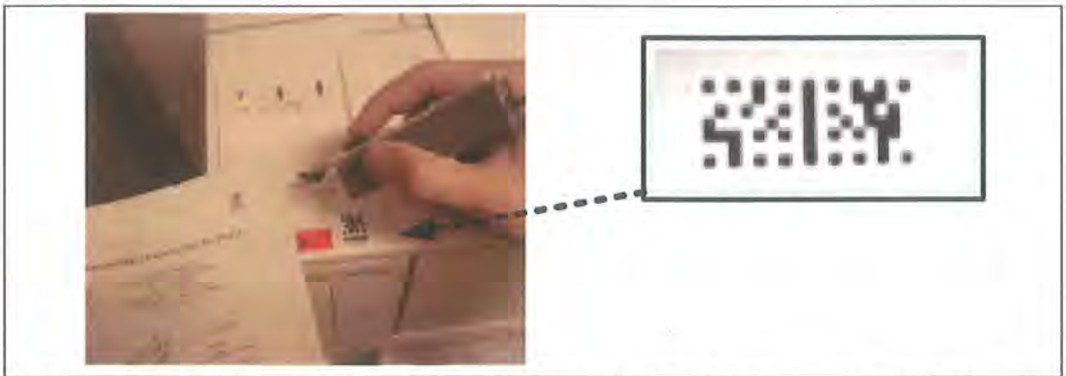
Figure 46: Field Mouse and Paper Remote-controller

Since barcodes are used merely as an ID tag, 1D-barcodes are sufficient in this application. Although, 2D-barcode technology is not utilized in the system, this project is worthy of special mention as this approach has an impact on subsequent studies in the same area, demonstrating the usability of barcode technology in the field of ubiquitous computing.

II. CyberCode

Rekimoto and Ayatsuka (2000) also address the ID tagging systems using a visual tag called CyberCode. The major differences between the two systems are that the FieldMouse uses 1D-barcode and can be used on only 2D surfaces, whereas the newly invented 2 dimensional CyberCode is capable of 3 dimensional (3D) position tracking as well as 2D position detection. Although CyberCode is not specifically invented for the mobile devices such as a mobile phone with a CCD camera, the code is designed to be recognized by such cameras. Thus, with the growing popularity of camera phones, this enhanced the possibility for the prevalence of "augmented-reality ready" mobile devices (Rekimoto & Ayatsuka, 2000).

The CyberCode recognition algorithm consists of two parts: the recognition of the ID of a tag and the determination of 3D position of the tag in relation to the camera used as an image processing device, and vice versa. The mechanism enables devices utilized as a tag reader to retrieve data encoded in tags, activate the associated actions, and attach information to tags. CyberCode also performs physically extended concept of drag-and -drop, working as operands for direct-manipulation operation (see, Figure 47).



An ID-aware pen is used to perform a "drag-and- drop" between physical objects.

Figure 47: CyberCode application: Drag and drop

4.2.2 Ubiquitous Computing

In recent years the term "Ubiquitous Computing" has come into its own. The term was coined by Mark Weiser (Mattern, 2004), who perceived the personal computers at the time so dominant that they colonized even humans' lives as well as their desktops (Weiser, 1991). The goal of ubiquitous computing is to create an environment where the connectivity of devices is embedded in such a way that the connectivity is always available unobtrusively (Weiser, 1991). Some researchers have attempted to use 2D-barcodes to make the ubiquitous computing world a reality.

I. TRIP

Ipiña1, Mendonça2 and Hopper (2002) have introduced Target Recognition using Image Processing (TRIP), a low-cost and easily deployable vision-based sensor technology. TRIP addresses the issues that are quite similar to the ones seen in CyberCode application. A combination of 2D circular barcode tags (ringcodes) (see, Section 3) and inexpensive CCD cameras such as web-cam or closed-circuit television (CCTV) cameras that plugged into standard PCs is used to detect identifier (TRIP code) and pose (location and orientation) of a target in real-time with respect to the viewing camera in the system (Ipiña1, et al, 2002). A distinctive feature of TRIP code is its circular shape, which works better for the identification and 3D localization of the object than the other shapes (e.g. square) using a visual sensor (Ipiña1,et al, 2002).

Although there are a lot in common between TRIP and CyberCode system, the former is different from the latter in the respect that the main focus of CyberCode system is to apply it to the domain of AR, whereas the goal of TRIP system is to create a Sentient

Computing (SC) environment, which is a form of ubiquitous computing. In contrast to the CyberCode system where identifiers are often statically set and the relevant information is superimposed on the 3D location detected, TRIP code is used to dynamically track the identifier attached to the object in motion, and to provide the real-time corresponding 3D location information to make the sentient computing environment a reality. Considering the high processing demand of vision-based sensors and the continuous TRIP operations, three different TRIP sensor operating modes are offered by the system according to the necessity of image processing for efficient and effective operations. These are default-mode, saving-mode, and real-time mode. In order to manipulate and distribute the sensor data provided by the technology, an event-based distributed architecture has been devised in the TRIP system (Ipiña1, et al, 2002), which relies on a CORBA infrastructure and a centralized recognition engine named "TRIPparser" (Rohs, 2004). To make it practical, consequently, the system requires a fully networked environment equipped with sufficient numbers of cameras and PCs in accordance with the scale of the SC environment.

In these studies, designing AR systems and/or ubiquitous computing environment have higher priority than inventing a better 2D-barcodes improving their capability. The use of barcodes is merely a mean to realize the proposed applications. Accordingly, traditional 1D-barcodes are utilized in the FieldMouse applications where the barcode technology works as an ID to track 2D location. Although 2D-barcodes were invented in the other approaches (i.e. CyberCode and TRIP code), their foci were designing AR and SC systems, respectively. Rekimoto and Ayatsuka (2000), for example, referred to the effectiveness of using 1D-barcodes as an alternative, especially in an application that handles a large number of existing products. The role of 2D-barcodes in such applications is to work as IDs for the tagging systems and capabilities of those codes are not as important as of their counterparts utilized in applications in certain industries. Rekimoto and Ayatsuka (2000) claimed that a large amount of data no longer have to be encoded into ID tags in such an environment where network ready devices can provide seamless connectivity, as opposed to Yeh and Chen (1998) who, as the inventors of a 2D-barcode, put more emphasis on enhancing 2D-barcode capability and appreciate 2D-barcodes being a portable database rather than only a key to databases.

The economical aspect of barcode technology may attract these researchers more than the technological aspect as nearly all researchers (if not all) who attempt to utilize barcode technology for their applications mentioned the economical advantages of using it in comparison with other technologies such as Radio Frequency Identification (RFID) tags, resonant tags, and infrared IDs. Commonly available PCs and cameras with VGA (640×480 pixels) resolution are utilized in these studies and the emphasis is the inexpensive operation of the systems.

In terms of creation of ubiquitous computing environments, however, these systems have a common shortcoming: lack of mobility of devices that provide network connectivity. That is, these systems are only available in the places where the required devices (e.g. cameras and PCs) are sufficiently integrated in the environments. If one has to be in certain places to experience ubiquitous computing consciously, then that is not true ubiquitous computing (Weiser, 1991). To achieve the incarnation of the ubiquitous computing in a true sense, therefore, network devices that have portability such as mobile phones and Personal Digital Assistances (PDAs) are utilized in the following research. These devices are used not only as a network medium but also as an image processing device.

4.2.3 Integration of 2D-barcode and Wireless Mobile Devices

With the integration of the enhanced capability and its popularity, mobile phones have contributed a great deal to human lives, not only via human-to-human communication but also through human-to-technology interaction such as short message services (SMS) and emails (Mattern, 2004). Consequently, they have established a position as a pervasive computing tool. That is, mobile phones are within reach of their users most of the time and are thus available in many everyday situations (Rohs, 2004), being always ready for providing users with connectivity.

I. iGrocer

Shekar, Nair, and Helal (2003) proposed a grocery shopping system called iGrocer where a smart phone is used as a scanner as well as a portable device that can provide wireless connectivity. The system enables healthy food choice, coupon management, queue-less secure checkout with the use of credit card, and more importantly, real-time interaction with the map that shows the location of each product. The phone also displays information obtained through the link to the relevant databases as needed (Shekar, Nair, & Helal, 2003). Although it addresses the capability of the system that requires both barcode technology and portable network devices such as smart phones, this approach is different from other studies of ubiquitous computing in that

1D-barcodes are used in the system, as they are used in the same way in supermarkets. The iGrocer system merely provides a type of on-line shopping within the wireless network provided by a smart phone without addressing the potential capability of barcode technology as in the other studies. On the other hand, the capability of barcode technology is explored together with mobile devices with network connectivity in other studies. 2D-barcodes are often used as visual entry points into virtual world in such systems.

II. QR Code

QR Code invented by Denso Wave in 1994 is one of the earliest 2D-barcodes that are utilized in applications where a combination of camera-equipped mobile phones and 2D-barcode technology is required (DENSO WAVE INCORPORATED, n.d.). The use of QR code in this way may not be the original intention of the inventors of the code. However, technology often thrives when people start using it for the purposes other than the ones intended by its inventors (The Economist Newspaper Limited, 2005). Indeed, applications developed using QR code and camera phones have become widely accepted by general users in Japan and a number of companies offer camera phones that have a reader for QR code as one of the functions (Rohs, 2004).

III. Semacode

Unlike QR code, Semacode is introduced specifically targeting camera phone users. Semacode has utilized the public domain standard Data Matrix 2D-barcode format to encode plain-text Uniform Resource Locators (URLs) (Semacode.org, n.d.). Data Matrix is a robust code that can store hundreds of characters (a maximum theoretical density of 500 million characters to the inch), recovering up to 50% of lost data due to damage (RVSI Acuity CiMatrix, n.d.). By using camera phones that support Semacode, URL will be automatically read out of the code and be presented in the phone browser (Semacode.org, n.d.).

In some approaches, the existing codes are used to develop applications that target general users of camera phones. QR code and Semacode are the examples of such approaches. There are some researchers, on the other hand, who have adapted the existing 2D-barcodes for the use for the applications they have devised. A derivation of the TRIP code called SpotCode, is introduced by Madhavapeddy, Scott, Sharp, and Upton (2004). Another example is Visual tag that derived from both TRIP and SpotCode (Scott, Sharp, Madhavapeddy, & Upton, 2005). This may exemplify how a 2D-barcode can evolve.

IV. SpotCode

SpotCode has been utilized for camera-equipped mobile phone applications that enable human-computer interaction. Precisely, SpotCodes, a camera phone, and Bluetooth technology are required for the system to work. The code contains two pieces of information: service-identifier and a data-block. The former informs the camera phone of the relevant Bluetooth service to a certain code and the latter consists of application specific information (Madhavapeddy, et al, 2004). The camera phone is used to decode the information and short-range wireless communication provided by Bluetooth services enables data transmission between the code and the camera phone. In addition to the three core elements described above, practically, PCs that supports Bluetooth services and active displays on which SpotCodes are placed, are also necessary for the system. Figure 48 shows the data flow and the components required in the system.

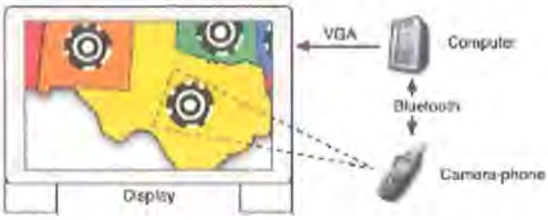


Figure 48: Data Flow in the system

Source: Using Camera-Phones to Enhance Human-Computer Interaction. (Madhavapeddy, Scott, Sharp, & Upton, 2004).Retrieved June 05, 2005, from, ubicomp.org/ ubicomp2004/ adjunct/demos/madhavapeddy.pdf

Through the wireless communication established, the phone constantly transmits the data-block of the codes along with the current (x, y) positions, sizes, and orientation at which the codes are detected, relative to the position of the camera (Madhavapeddy, et al, 2004). As a result, the system allows a Bluetooth-enabled camera phones to control active displays as a sophisticated pointing-device regardless of shape and size of computers. The code also works as a user interface for devices without display or input capability of their own, using the phone's own display and keypad as the point of human-computer interaction (Madhavapeddy et al, 2004).

V. Bluetooth Device Discovery

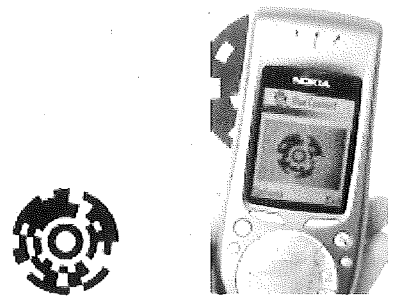
The same research group has further explored the usability of visual tags in Bluetooth-based wireless communication environment. The main focus of the previous research was the human-computer interaction based on the barcode technology and camera phones with short-range wireless connectivity provided by Bluetooth technology.

On the other hand, the focal point of the new study is on how effectively visual tags can be used to bypass Bluetooth device discovery. According to Scott, et al. (2005), despite the proliferation of mobile devices with Bluetooth capability, the use of Bluetooth as a networking technology for publicly accessible mobile services has been limited due to its inappropriate and ineffective way of device discovery. Through the implementation of an end-to-end Bluetooth-based mobile service framework, Scott, et al. (2005) have demonstrated the effectiveness of the tag-based connection-establishment technique developed by the group over the standard Bluetooth device discovery model in terms of speed, usability, and scalability.

For the purposes of the research, the circular tags used in the system, initially inspired by TRIP code tags, have been improved mainly on two points:

i. The number of bits encoded in a single tag has been increased by adding extra data rings (i.e. it becomes 4-rings, adding two extra rings); and
ii. An explicit sync-marker is added to specify tag orientation.

The image-processing technique developed for SpotCode reading has also integrated into the proposed system, which general users can freely download and try. Each code contains a 48-bit Bluetooth Device Address (BD_ADDR) and a 15-bit application-specific data (see, Figure 49, p.102).



Left: A Visual Tag encoding a 48-bit BD ADDR and 15 bits of application-specific data;
Right: Using the tag reader on a Nokia 3650 camera phone.

Figure 49: Visual tag and tag reader

Source: Using Visual Tags to Bypass Bluetooth Device Discovery. (Scott, Sharp, Madhavapeddy, & Upton, 2005).Retrieved July 07, 2005, from http:// portal.acm.org/ citation.cfm?doid=1055965

In the tag-based device discovery system, a device being detected must have a tag attached to it: either as physical print format or image displayed on the device's screen (e.g. as the default wallpaper). To establish Bluetooth connection between two mobile phones, for example, one is required to aim his/her camera phone at the tag attached to another device with which he wishes to communicate. Once the image is captured by the camera phone, BD_ADDR of the phone being detected is yield and the connection between the two devices is immediately established. In the case when the 15-bit application-specific data is encoded in the tag as well as the device address, the associated service is also provided by the single image-processing. Hence the system provides not only faster Bluetooth connection establishment, but also easier service selection than the standard Bluetooth device discovery model where a user is required to first select the device's name of the phone with which he wishes to communicate among all the listed device names, and then make a service selection among all available services. The system works efficiently particularly when the user is aware of the physical location of the device with which he wishes to establish the connection.

VI. SiB

A mechanism similar to the Bluetooth device discovery system described above applies to Seeing-Is-Believing (SiB) authentication system proposed by McCune, Perrig, and Reiter (2005). In general, it is rater difficult to ensure which device is at the end of a wireless connection (McCune, et al, 2005), and thus wireless communication is often considered to be vulnerable against malicious attacks such as a Man-In-The-Middle (MITM) attack. In the SiB system, as one of the solution, the combination of barcode technology and camera phones is used as a visual channel for human-verifiable authentication. In order to implement authentication between two camera phones (i.e. A and B) using SiB protocol, for example, the following procedures will take place.

- **i.** Each phone computes a commitment to their public keys and generates a 2D-barcode encoding this commitment.
- **ii.** Both A and B take turns displaying and taking snapshots of their respective 2D-barcodes (i.e. pre-authentication phase). Both devices now hold commitments to the other device's public keys.
- **iii.** A and B exchange their public keys over the wireless communication link.
- **iv.** Each device performs the same commitment function over the other device's public key, ensuring that the result matches the commitment that was received over the visual channel (i.e. mutual authentication completion).

(McCune, et al, 2005)

This authentication procedure is conducted visually in the presence of the users and their devices, and thus they can be sure that their devices are communicating with their intended ones (i.e. demonstrative identification). It is tangible visual tags such as 2D-barcodes that enables such strong authentication integrated into the authentication provided by security mechanisms described above. This attempt is important in that it demonstrates the potential use of the integration between 2D-barcode technology and mobile phones in various contexts.

VII. Visual Code

In the SiB system, the barcode format of Visual Code and the relevant image processing algorithm has been adapted. Visual Code is invented by Rohs and Gfeller (2004). The most important aspect of this approach is that the code is explicitly developed for the use of camera-equipped mobile phone applications from scratch. Accordingly, the limitations inherent to camera phones such as low quality built-in cameras, the image distortion derived from the phone mobility are specifically addressed by developing a 2D-barcode that is suitable for the use of camera phones. It is presumed that the nature of objects (e.g. paper, wall display) and the features related to their intended applications were also considered.

According to Rohs (2004), the quality of colour image generated by the camera on a mobile phone is rather poor (i.e. VGA resolution = 640 × 480 pixels or less) and it often lacks a floating point unit. These features determine the minimal cell size of the code, which is considerably large in comparison with most available 2D-barcodes (Rohs, 2004). This may be due to not only the camera phone limitation but also the applications developed by Rohs (2004), which is extension of visual tag system. As it has been seen, the goal of visual tag systems is the realization of AR and/or ubiquitous computing. Hence, human-computer interaction is often involved. In order to interact with computing devices such as large-scale wall, which can be located either inside or outside the building under varying light conditions, the code should be sufficiently large and distinctive to be recognized from a distance. This also affects the selection of black and white colour of the code, which can produce clearer contrast compared to the use of colour code (Rohs, 2004).

The symbols scanned by a camera phone may appear at any orientation in the camera image due to the mobility inherent in camera phones. Hence, a visual code for camera phones should be angle-free. This shortcoming of the use of mobile phones, however, results in the proposition of the novel feature of the system. Rohs (2004) proposed the code coordinate system, visual detection of phone movement, and the determination of the rotation angle and amount of tilting in his research. By the integration of these features, a camera phone acts as an optical mouse, and it enables human-computer interaction. In addition, the system allows users to obtain multiple information items located at known code coordinate positions relative to a single code tag, by clicking the single tag (Rohs, 2004).

4.3 Summary

The barcode technology, especially 2D-barcode technology is considerably new. The trend observed in early studies on this topic is similar to the one seen in most emerging industries and organizations. That is, the researchers have attempted to either enhance the capability of a 2D-barcode or develop applications that exploit their ability, especially their high data capacity.

Considering both technological and economical aspects (i.e. the possibility of inexpensive, yet effective system development), the concern of researchers has moved to carry out the visual tagging systems using barcode technology, 2D-barcodes in most cases. Their goals are the realization of Augmented Reality systems and/or ubiquitous computing. In order to make these systems into reality, fully networked environment was necessary in the early stage of the development of such systems.

With the integration of CCD camera, mobile phones have become networked personal image capture devices. Inspired by the emergence of such a desirable device, researchers have sought to explore the potentials of the integration of two new technologies, namely, 2D-barcode and camera-equipped mobile phone through the development of novel applications. Summary of studies on barcode technology and the relevant applications are illustrated in Figure 50 (p.107).

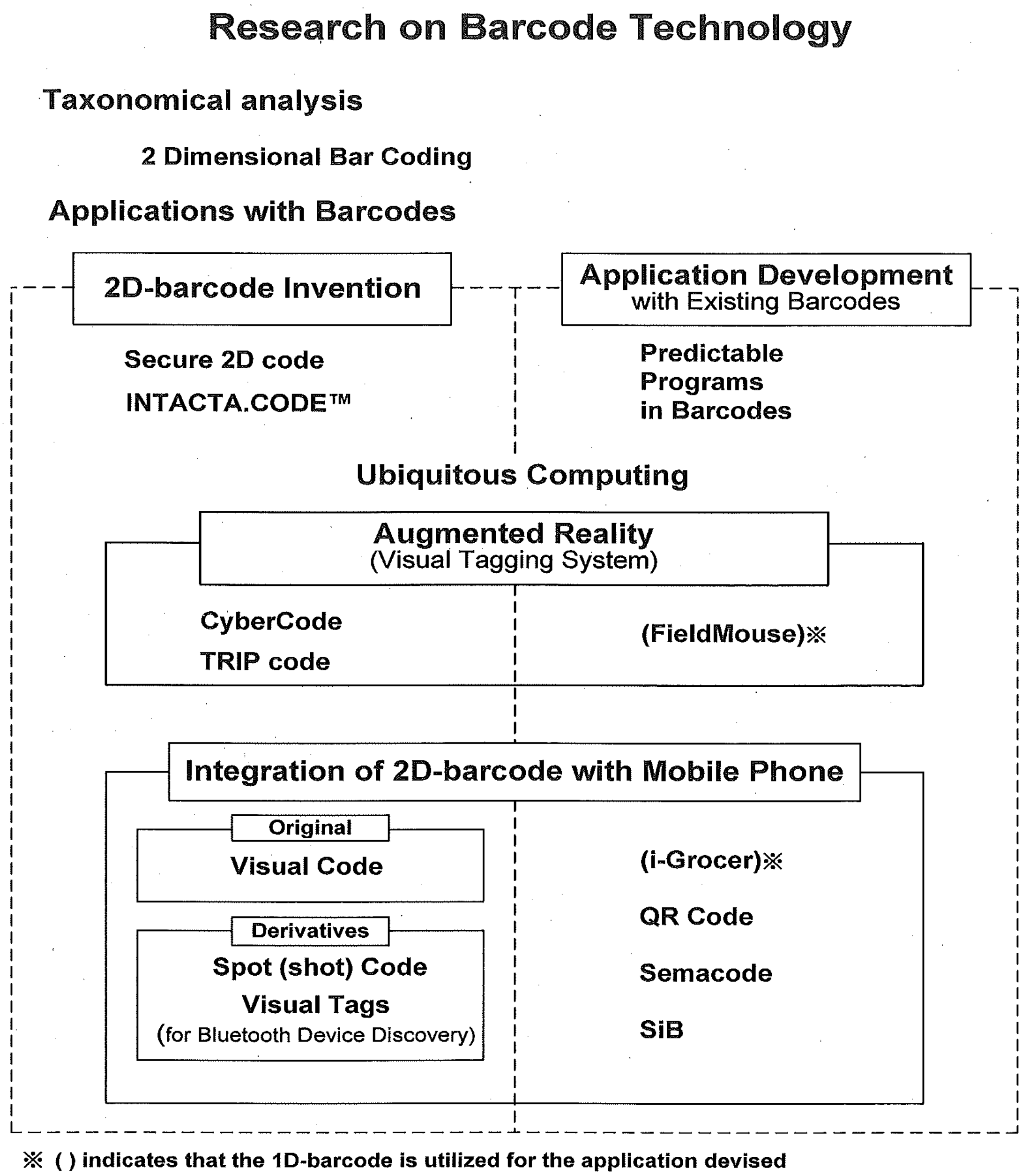


Figure 50: Summary of studies conducted on Barcode Technology

5 Study for Two Dimensional Barcode Standardization

This study consists of two phases. In the first phase, the study involved qualitative approach, whereas quantitative approach is taken in the second phase.

5.1 The First Phase Assessment

In the first assessment, all existing and accessible 2D-barcodes were addressed. To measure which 2D-barcode is most eligible as potential standard, requirements to select a standard 2D-barcode are first set and then each code is examined in terms of criteria established. These criteria are set in the light of mainly the functional limitations of camera phones in general use today. In addition, application-specific features and the nature of objects are also considered.

5.1.1 Assessment Method

Each code is examined against the criteria set. The information to assess each 2D-barcode will be mainly obtained via publicly accessible media such as the web sites provided by companies/organizations.

Prior to this study, the preliminary review of the topic (i.e. the features and utilization of the existing 2D-barcode) was conducted and it has revealed that information of some 2D-barcodes is hard to come by. For the completeness of the study, an electronic survey was also conducted. The electronic survey was carried out with companies, organizations and inventors that are relevant to each 2D-barcode. Survey letters were mailed to the electronically inaccessible companies. It should be noted that there is a possibility that the 2D-barcodes whose detailed information is obtained through the survey will satisfy more criteria than those whose participation is declined.

5.1.2 Criteria setting for the assessment

In order to determine the minimum requirements for the selection of a standard 2D-barcode, factors that require certain attributes of the 2D-barcode for mobile phones are considered and identified. These factors are:

I. Use of mobile phone for image processing;

II. Nature of objects;

III. Applications that are commonly offered for end users with a camera phone; and

IV. Multi-language encoding capability.

In addition to the four factors,

V. Ownership domain of the 2D-barcodes

is included as one of the factors since whether or not the code is publicly available may have some impact on the final decision.

I. Use of Mobile Phone

Although the quality of images taken by a camera equipped mobile phone has greatly improved, yet not all camera phones have 2 or 3 mega pixel camera units. Hence, it is important to consider the resolution of the camera in mobile phones in establishing criteria for selecting a standard 2D-barcodes for mobile applications. In fact, the resolution of the mobile phone camera, which acts as a barcode scanner, is one of the key factors to determine the density of the 2D-barcode (Barnes, Bradshaw, Day, Schott, & Wilson, 1999). That is, the density of 2D-barcodes is limited by two factors; one is the ability to generate the small cells of the 2D-barcode, another is the ability to scan a large density 2D-barcode. The former usually depends on the precision of a printer, whereas the latter is dependent on the resolution of an imager (Auto ImageID, 1999 cited in Barnes, et al., 1999). Consequently, the resolution of a camera unit in the mobile phone has a great impact on determining the reasonable data density of the standard 2D-barcode for mobile applications. There are still many camera phones which can only generate low to medium quality images; equivalent to, or less than VGA (640 × 480 pixels) (Rohs, 2004). Accordingly, the standard 2D-barcode should be capable of producing codes that can be precisely scanned by mobile phone with VGA camera resolution or even less.

On selecting a standard 2D-barcode, the mobility inherent in mobile phones should also be considered (Rohs, 2004). Thus, 360 degrees read flexibility of the 2D-barcode is an important attribute.

II. Nature of Objects

2D-barcodes can be produced on different types of materials, e.g. paper, walls, and the display screen of a computer depending on the code usage. However, they usually appear on the physical objects and there may be possibility for 2D-barcodes to be damaged. Accordingly, powerful error correction ability is required to ensure the integrity of the content of the barcode (Yeh, & Chen, 1998).

Due to its mobility and printability regardless of materials, it is also possible that a 2D-barcode is located outside where neither reasonable light nor propinquity is always guaranteed. A time table of buses may be a good example. Providing that a 2D-barcode contains the bus time table, it is not always in reach of all people who are waiting for a bus. One may have to capture the image at a distance under poor lighting conditions. The increase in size of the code may be one of the solutions for this scenario. It may also depend on the camera performance. A mobile phone camera with flash function, for example, may produce clearer image than those without light. However, the initial purpose of this standardization is to provide the third-party software vendors with the basis for application development, which in turn make more applications available for more users. The criteria for a standard barcode, therefore, have been developed based on camera phones with no flash and zoom lens. That is, a symbol which is tolerant of less light and of further distance is higher possibility to be chosen as standard in terms of these criteria. In addition to the data correction ability, hence, how distant and how bright a 2D-barcode can be precisely read is worthy of the consideration.

III. Applications

The examination of current 2D-barcode applications utilized for the use of camera phones has revealed that some 2D-barcodes are used to exchange the personal ID on business cards. Some applications involve payment such as on-line shopping and e-ticket booking. Such applications demand sufficiently secured codes and this brings forth the importance of security feature for the standard 2D-barcode.

The use of security techniques such as encryption requires larger data capacity. Greater data storage may be important attributes for some applications such as ring tone download. However, the demand for higher data density is not only relevant to application factor but also other factors (e.g. nature of objects and multi-language support). Therefore, data density is not regarded as application-specific attributes.

IV. Language Encoding Capability

The purpose of this study is to provide the third party vendors and end users with a global standard 2D-barcode for mobile phone applications. Accordingly, the ability to encode multi-language is considerably important. This dictates the capability of a standard 2D-barcode to encode the Unicode as well as the ASCII character sets or equivalent techniques enable multi-language encoding.

V. Ownership Domain

2D-barcodes are divided into to two ownership domains: proprietary and public. An organization, which owns a particular 2D-barcode, may allow free use of its patented code. Hence, a 2D-barcode that belongs to a proprietary domain does not necessarily mean that it requires users to obtain permission for using the 2D-barcode. However, it depends on the organization that owns the 2D-barcode and there may be difference in accessibility to the codes. Thus, ownership is included as a criterion in the requirement of the study.

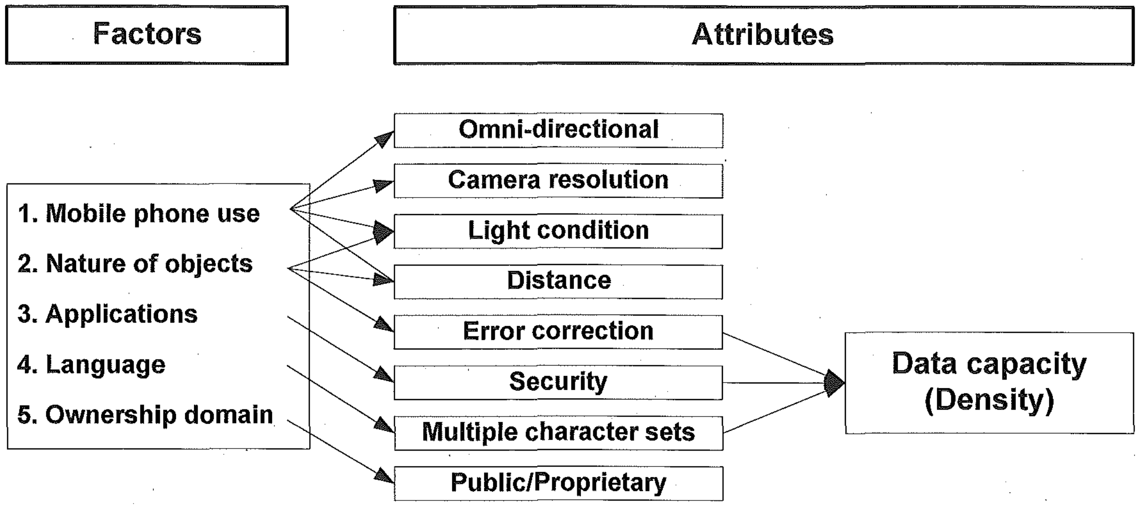


Figure 51: F actors and attributes considered for the standardization of 2D-barcode for camera-enabled cell phone applications

The diagram in Figure 51 shows what factor requires what attribute(s), which are considerations in this study. Since the standardization is for camera-integrated phone applications, for example, the capabilities and limitation of camera equipped phones should be firstly considered. Hence, the use of camera phones is presented as the most important factor. Likewise, other factors are listed in the order of importance in Figure 51, from the top to the bottom. Some factors dictate more than one relevant attributes and some attributes require the other attribute to make it possible. For example, additional data capacity is required to make 2D-barcodes error-resistant, secure and multilingual.

To measure which 2D-barcode is most eligible as standard, nine requirements were identified and set as criteria. As previously stated, ownership domain has been added as one of the criteria to see accessibility of each 2D-barcode before the final selection of a standard 2D-barcode for camera phone applications is made.

2D-barcodes can be classified into two broad categories by their structure as well as ownership domain: stacked codes and matrix codes. In addition to the requirements identified above, type of symbology (i.e. either stacked or matrix) is looked into in the assessment. This is to address the common features in the same code type and differences between stacked and matrix barcodes. Almost all (if not all) the 2D-barcodes that have been utilized for the camera phone applications belong to matrix type. The investigation by code type may provide the strengths and shortcomings common in each symbol type and explain why only matrix 2D-barcodes have been utilized for camera phone applications. This may also open a door for stacked 2D-barcodes to be used for mobile phone applications by adding features that is crucial for those applications.

Strictly speaking, each code is examined in terms of eight criteria exclusive of the ownership domain and code type. The more criteria a code satisfy, the higher possibility it can be selected as a standard 2D-barcode.

5.1.3 First Assessment Results and Observations

The results of the first assessment are presented in the following tables. The 2D-barcodes that meet equal to or more than 4 criteria in public and proprietary domain are presented in Table 7 and Table 8, respectively. Table 9 shows the result of 2D-barcodes which are specifically designed for mobile phone applications. Table 10 shows how many 2D-barcodes satisfy how many criteria classifying in terms of symbol type and ownership domain. The result for all sample symbols is provided in Table 30 in Appendix 5 (p. 166).

Table 7: Public 2D-barcodes that meet equal to or more than 4 requirements

2D- Symbology	No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
Secure 2D code	7	M	O	O	O	/	O	O	O	O	N/A	2 security layers, Data hiding
Data Matrix	7	M	O	O	O	O	O	O	/	O	U	Scalable in size.
Semacode	6	M	O	O	O	O	O	O	/	/	U	
Mobile code	6	M	O	O	/	/	O	O	O	O	U	Scalable in size.
MS-CODE	6	M	O	O	/	/	O	O	O	O	U	Scalable in size.
QR Code	5	M	O	O	/	/	O	O	/	O	U	Scalable in size. Can be divided.
Micro QR Code	4	M	O	O	/	/	O	×	/	O	U	Scalable in size.

※ Note: 2D-barcodes that are not proprietary are included in this table. Patented codes that are allowed to use freely are regarded as public codes.

Table 8: Proprietary 2D-barcodes that meet equal to or more than 4 requirements

2D- Symbology	No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
DataGlyphs	6	M	O	O	O	/	/	O	O	O	R	Adjustable size, shape and color
VeriCode®	6	M	O	O	/	/	O	O	O	O	R	Scalable in size.
VSCode®	6	M	O	O	/	/	O	O	O	O	R	Scalable in size. Greatest in density.
CP Code	5	M	O	O	/	/	/	O	O	O	R	
INTACTA.CODE	5	M	/	O	/	/	O	O	O	O	R	Scalable in size. Data compression.
Datastrip Code	4	S	×	O	/	/	/	O	O	O	R	Resistant to alteration.
MiniCode	4	M	O	O	/	/	O	O	/	/	R	Scalable in resolution.
Snowflake Code	4	M	O	O	O	/	/	O	/	/	R	

Table 9: 2D-barcodes specifically designed for camera phone applications

2D- Symbology	No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
ShotCode (SpotCode)	2	M	O	/	/	/	O	/	/	/	/	Works irrespective of lens quality.
VisualCode	3	M	O	/	/	/	O	O	/	/	/	Code coordinate system.

Note: When no information is provided, an oblique line is placed in the box (i.e. ⧄)

Legend:

No. The number of requirements that each 2D-barcode satisfies.

1. Type: (Stacked: S or Matrix: M)
2. Omni-Directional: (Yes: ○, Otherwise: ×)
3. Error Correction Ability: (Yes: ○, Otherwise: ×)
4. Light Condition: (Legible under widely varying lighting conditions under very low contrast: ○, Otherwise: ×)
5. Distance: Clearly legible at approx. 10 cm away from the code (Yes: ○, Otherwise: ×)
6. Support VGA (640x480 pixels) Resolution (i.e. can be read by a camera with VGA resolution often found in cell phones (Yes: ○, Otherwise: ×)
7. Data Capacity/Density : (High: ○, Low: ×)
8. Security: A code itself is secured by security techniques (e.g. data encryption); exclusive of security provided by additional operations (e.g. Use of authentication sever) (Yes: ○, Otherwise: ×)
9. Multi-Language: (Support any languages other than English as well as English: ○, Otherwise: ×)
10. Domain: (Public: U, Proprietary: R)
11. Additional Feature(s) (Advantageous features of each code if any)

Table 10: 1st Assessment Result presenting how many 2D-barcodes meet how many criteria

Criteria	Domain	2D-code			Total	Total
		Public	Proprietary	N/A		
2D-barcodes that satisfy all requirements	S※1	0	0	0	0	0
	M※2	0	0	0	0	
2D-barcodes that satisfy 7 requirements	S	0	0	0	0	2
	M	1	0	1	2	
2D-barcodes that satisfy 6 requirements	S	0	0	0	0	6
	M	3	3	0	6	
2D-barcodes that satisfy 5 requirements	S	0	0	0	0	3
	M	1	2	0	3	
2D-barcodes that satisfy 4 requirements	S	0	1	0	1	4
	M	1	2	0	3	
2D-barcodes that satisfy less than 4 requirements	S	4	0	3	7	19
	M	5	2	3	10	
	N/A	0	2	0	2	
Total	S	4	1	3	8	34
	M	11	9	4	24	
	N/A	0	2	0	2	

※1 S: Stacked, ※2 M: Matrix

All the 2D-barcodes are ranked in accordance with how many criteria numbered between 2 and 9 can be satisfied by each code. The more criteria a 2D-barcode can satisfy, the higher possibility the code can be chosen as a standard barcode for cell phone applications.

The main findings of our assessment are described as follows:

I. Most 2D-barcodes satisfy two criteria; error correction ability (relevant criterion no. 3, only numbers will be shown hereafter) and data capacity/density (7). However, the degree to what extent the error can be corrected varies among the codes, and also within the same code. For example, the amounts of Reed-Solomon error encoding of Aztec Code vary from 5% to 95 % depending on the code size and the error collection level selected by the user. Data capacity also varies depending on versions of the code, security levels, size of minimum unit (e.g. a cell), and so forth. The more data are encoded, the larger a 2D-barcode becomes. With the space limitation, data density should increase, instead. As has been seen, density of a code is highly dependent on the quality of printer and imager (i.e. a camera unit in a mobile phone in this case). The ability of camera phones as a data capture device is often inferior to the scanners used in industry. Once a code density exceeds the capability of a camera as an imager, the code cannot be successfully decoded. That is, no further additional data capacity is possible. For example, only up to version 10 of QR code is utilized for mobile phone applications (NTT DoCoMo, Inc., 2005) even though the maximum data can be encoded by its highest version of 40 (DENSO WAVE INCORPORATED., 2003) due to the limitation of camera phones. Hence, a 2D-barcode that has any kind of data correction ability is considered to meet the data correction criteria. As for the data capacity, any codes whose data capacity is roughly equivalent to the version 10 of QR code with 15 percent of data correction level (i.e. the maximum number of characters: 513 in numeric, 311 in alphanumeric, and 213 in binary = 8bits) are regarded as satisfactory.

II. Nearly all matrix codes can be omni-directionally read, while there are few stacked 2D-barcodes that are capable of omni-directional reading (2). This explains the reason why all 2D-barcodes that have been utilized for mobile phone applications belong to the matrix barcode type.

III. The description regarding light condition (4) is hardly found in nearly all 2D-barcodes. This feature is important when a user interact with the objects without reasonable brightness (e.g. a user attempts to capture a 2D-barcode that contains transport time table at night time). It also depends on the function of the camera phone used.

IV. The same applies to the distance (5). The degree of distance a 2D-barcode can be accurately read is not mentioned in most code description. This also hinge on the capability of a camera. However, a code may not be suitable for a standard 2D-barcode for mobile phone applications if the code needs contact or close proximity to be successfully read.

V. There are some 2D-barcodes which are scaleable in size. Some 2D-barcodes can be divided into smaller codes. These codes may support all camera phones, ranging from camera phones with low resolution (e.g. VGA or less) to those with mega-pixel camera phones (6).

VI. 2D-barcodes are considered to be secured only when these 2D-barcodes themselves are tenable using security techniques (e.g. data encryption). That is, 2D-barcodes which are protected by the use of security mechanisms (e.g. through an authentication server) are not considered as secure 2D-barcodes. Nevertheless there are more codes that satisfy the security criterion (8) than expected.

The information regarding light condition and distance are hard to find from the accessible literatures. It is also difficult to ensure whether a 2D-barcode can be successfully captured and decoded by a camera phone with VGA resolution. This may be due to the fact that most 2D-barcodes are not devised for image capture devices such as mobile phone cameras but are designed for dedicated scanning readers. To examine each 2D-barcode more precisely, therefore, the second assessment (i.e. experiments) was planned and conducted. The detailed explanation on the second assessment is provided in the following section.

5.2 The Second Phase Assessment

5.2.1 Purpose of the 2nd Assessment

In the second phase, each 2D-barcode is experimentally examined. The purpose of the second assessment is to further examine 2D-barcodes that have potential to be chosen as a standard code. In the 1st assessment, the information on the light condition, distance, and whether or not a 2D-barcode support VGA camera resolution was hard to find. Hence, experiments to measure each code in terms of these three criteria have been conducted against the 2D-barcodes that satisfy at least four criteria or more. Visual Code and ShotCode that are specifically designed for the use of camera phones are included for the experiments.

The publicly accessible information on 2D-barcodes is mostly provided by the inventors, companies that developed the particular code, and associated companies/organizations. Hence, it is less likely that the negative information is provided. In addition, some inventors/companies may reluctant to impart their product information for commercial reasons. It may be desirable that second phase of the study, namely, the experimental approach can objectively cover this.

5.2.2 Assessment Method and Procedure

I. Sample codes for the experiments

The 2D-barcodes that satisfied at least four criteria or more in the first assessment are the sample for the 2nd experiments. Visual Code and ShotCode that are specifically designed for the use of camera phones are included for the experiments.

Both Mobile Code and MS-CODE are secured QR Code (DENTSUTEC, INC., 2005), (MEDIASTICK, INC., 2004). Micro QR Code is a small version of QR Code (DENSO WAVE INCORPORATED., 2003). Data Matrix code is used in Semacode (Semacode.org., n.d.) and VSCode® is a derivation of VeriCode® with greater data density (VERITEC, Inc., n.d.). In such cases, only the original 2D-barcodes that represent their derivative symbols are regarded as the subjects of the experiment. Hence, 3 public symbols, 7 proprietary symbols, and 2 symbols designed for mobile applications are put on the final list for the examination. The list of sample symbols is presented in Figure 62, in Appendix 6 (p.167).

II. Instruments for the experiments

In the second phase of the study, the experiments involve the use of the following equipments:

- A camera-integrated mobile phone (camera resolution: 640 × 480 pixels);
- A printer to produce each subject 2D-barcode;
- Publicly available 2D-barcode encoder/decoder where applicable;
- Cold Cathode Fluorescent Lighting sets;

- A scanner to re-produce the sample original 2D-barcodes; and
- MATLAB – a benchmark tool in image analysis written in MATLAB; A.

III. The procedure of the the experiments

The procedure of the experiments is described as follows:

i. Create two different sizes of each subject 2D-barcode: two squares with their sides approximately 2.50 cm (small sized 2D codes, S-symbols hereafter) and 5.0 cm (large sized symbols, L-symbols), respectively. The symbol creation was done in two ways. When on-line code generators are available, the codes were produced using the generators. Otherwise, the codes provided in information sources such as web sites are used by fixing the size without changing their data density.

ii. Print out the sample symbols using an inkjet printer, namely Epson Stylus Photo 810 Series (max. 2880 × 720 dpi).

iii. Capture the images at the most appropriate distance within 5-15 cm away from the target by a camera with VGA resolution built in a mobile phone (i.e. Sagem myC5-2, for specification, see Figure 63, Table 31, Appendix 7, p.168). This operation is done under three different light conditions: light with full power, half power, and no light. The lighting source used for the experiment is called Cold Cathode Fluorescent Lighting which was set as in Figure 52 (also see, Figure 53- i and Figure 54- i , ii , iii, and iv). When capturing samples in half light, it is administered in two ways: using the lights that are horizontally placed against the samples (light source 1 and 3 in Figure 52) and those vertically placed (light source 2 and 4). The experiments were administered in a room lit by ordinary lights on the ceiling (see, Figure 53- ii). That is, there is certain amount of light effect even when no Cold Cathode Fluorescent Lighting is used.

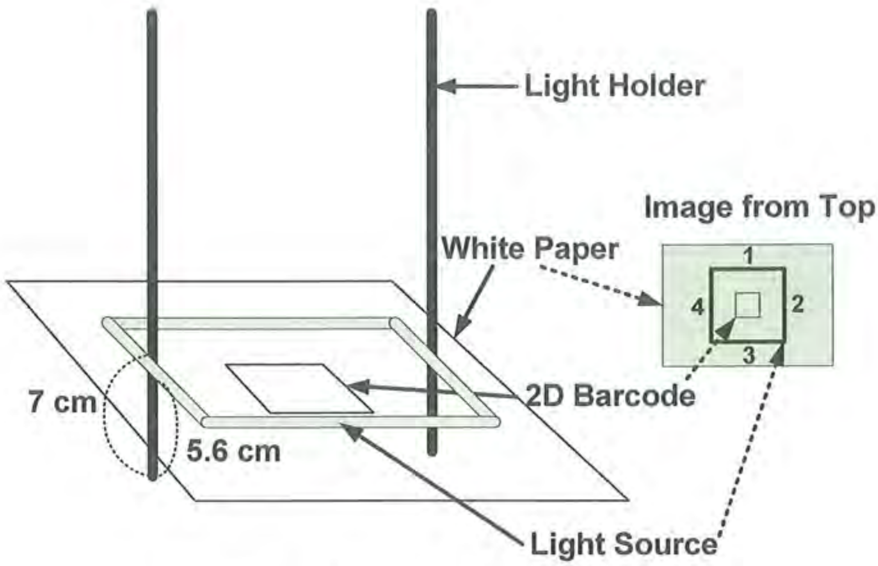
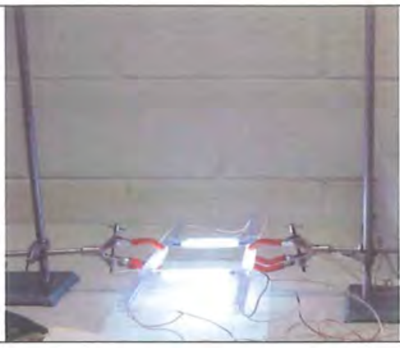


Figure 52: Target and Light Source

The light power in each light mode is presented in Table 11. Two types of light source and instruments used in the experiments are provided in Figure 53 and Figure 54, respectively (p.123).

Lighting condition	Current (A)	Voltage (V)
Full Light	1.6	15
Half Light (H)	0.9	15
Half Light (V)	9.0	15
No Light	0	0

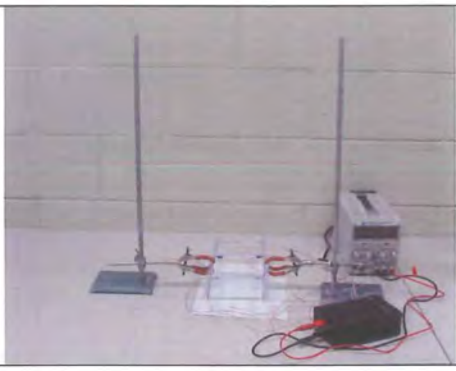
Table 11: Lighting Power in each mode



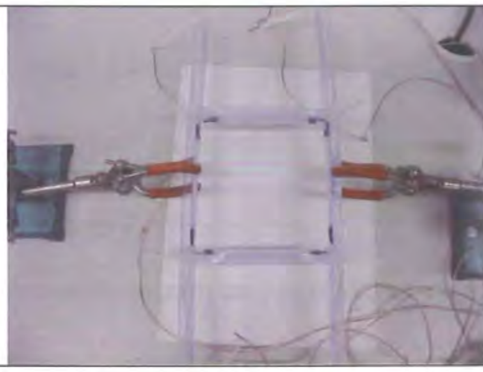
i : Cold Cathode Fluorescent Lighting

ii : Ordinary light on the ceiling

Figure 53: Light Source used in the experiments

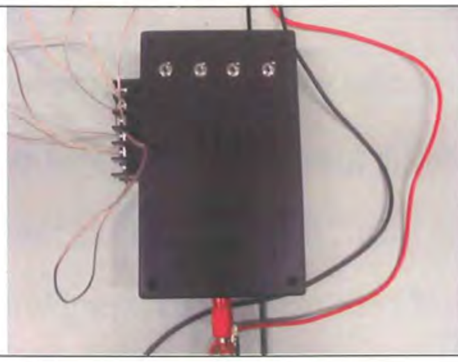


i : The devices set for the experiments



ii : Lighting top view

iii : Power Point with voltmeter



iv : Lighting Controller

Figure 54: Instruments used in the experiment

iv. Examine the images captured by the camera phone using benchmark tool in image analysis written in the scientific language called MATLAB. The symbol examination is administered in the following procedure:

I. Scan the original sample codes by a scanner and save the scanned images in the computer's hard drive, which is used for the symbol examination.

In order to use MATLAB for the image analysis, certain manipulation such as symbol resize and symbol crop should be done. In addition, the program allows only certain code format to process the analysis. Accordingly, it is necessary for some sample symbols be re-saved in the required format. Such manipulation may change the quality of original images. Hence this method is selected to minimize the effect of re-format, which may degrade the original symbol image.

II. Compare the original image and the images captured by a built-in camera of a mobile phone in three different light conditions, namely, lighting with full power, half power, and no power by calculating Peak Signal to Noise Ratio (PSNR) value of each captured image. PSNR is explained in the box below.

Peak Signal to Noise Ratio

PSNR:

The phrase peak signal-to-noise ratio, often abbreviated PSNR, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale.

Mean Squared Error (MSE) is a statistical measure of error, used to determine quality of compressed images. Mathematically equivalent to Peak Signal to Noise Rate (PSNR).

The PSNR is most commonly used as a measure of quality of reconstruction in image compression etc. It is most easily defined via the mean squared error (MSE) which for two m x n monochrome images I and K where one of the images is considered a noisy approximation of the other is defined as:

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} ||I(i,j) - K(i,j)||^2$$

The PSNR is defined as:

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) = 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right)$$

Here, MAX_I is the maximum pixel value of the image. When the pixels are represented using 8 bits per sample, this is 255. More generally, when samples are represented using linear Pulse Coded Modulation (PCM) with B bits per sample, MAX_I is $2^B - 1$.

Source: Peak signal-to-noise ratio (Wikipedia, 2005). Retrieved September 18, 2005, from http://en.wikipedia.org/wiki/PSNR

The higher PSNR value indicates that recreated image by a certain operation has less noise. Hence, it is possible to say that the higher the value of PSNR, the better quality an image has.

This is to measure the difference in fidelity of the representation of each 2D symbol captured in the different light conditions. It in turn indicates the sensitivity of each code to the light. Providing there are two symbols A and B. The PSNR value for each symbol in the different light condition is calculated as shown in Table 12 below (p.126).

Table 12: PSNR Value of Symbol A and B

Symbol	PSNR (dB)		
	Full Light	Half Light	No Light
A	30	25	20
B	30	29	28

The PSNR value for both A and B is the same (i.e. 30) under the full light condition. However, A only produces the PSNR value of 25 and 20 with half lighting and no lighting, respectively. On the other hand, the PSNR value of B dropped by only 1 when the light is cut into half and 2 into no lighting. It indicates that Symbol B is less likely to be affected by the light condition than Symbol A. Symbols with less sensitivity to light can produce better images regardless of the light available in any circumstance and is more suitable to be selected as a standard 2D-barcode.

5.2.3 Second Assessment Results and Observations

5.2.3.1 The Result of the Experiments

I. Distance

In the second assessment, the fidelity of representation of each symbol was tested in order to measure the strength of each code in terms of light condition, distance (i.e. how distant a symbol can be accurately captured by a camera phone), and the VGA resolution support. The PSNR values for each symbol under three different light conditions are presented in Table 32 for S-symbols and Table 33 for L-symbols (see,

Appendix 8, p.169 and 170). When a 2D-barcode contains more information, it is more likely that the cell size of the symbol as well as the size of the symbol itself become bigger. Therefore, L-symbols with larger cell sizes (Cell-Resized, CR-symbols) are also created for the 2D-barcodes whose generators are publicly available. This is to see how much the cell size of a symbol affects the outcome of the PSNR value. The outcome can be used for measuring the effect of scalability of the symbols. If the overall outcomes of CR-symbols are better than L-symbols, 2D-barcodes that are scalable in size are more advantageous. The PSNR values for CR-symbols are presented in Table 34 (see, Appendix 8, p.170).

The means of PSNR values obtained under the different light condition (i.e. full, half, and no light) were calculated for each 2D-barcode. The mean PSNR values of all the sample symbols were ranked in the descending order. The higher PSNR value indicates that the image captured by the built-in camera of a mobile phone is closer to the original symbol. Since all symbols are captured at the fixed distance (i.e. between 6.5 – 7.0 cm away from S-symbols and approximately 10 cm away from the L-symbols and CR-symbols) under the same variation of light conditions, the symbol with higher mean PSNR value as a whole can be accounted to be stronger against the distance under the same range of light conditions. That is, it is possible that such symbols can be captured more intact from a further distance. Hence, the mean PSNR value of each 2D-barcode was used to measure the distance criterion.

The mean PSNR values for S-symbols, L-symbols, and CR-symbols are presented in descending order in Table 13, 14 and 15, respectively. Each Table is followed by the bar graph. The bar graphs for S-symbols, L-symbols, and CR-symbols are provided in Figure 55, 56, and 57, respectively.

i. Mean PSNR Values for S-symbols

Table 13: Mean PSNR Value of S-symbols in Descending Order

No	S-ID	Symbology	PSNR
1	12	VisualCode	27.7404
2	8	Datastrip	27.6641
3	7	INTACTA	27.4221
4	5	VSCode®	27.2680
5	2	Data Matrix	27.2612
6	3	QR Code	26.8677
7	6	CPCode	26.7809
8	1	Secure 2D	26.5997
9	9	MiniCode	26.4221
10	11	ShotCode	26.4219
11	4	DataGlyphs	25.4444
12	10	Snowflake	24.6459

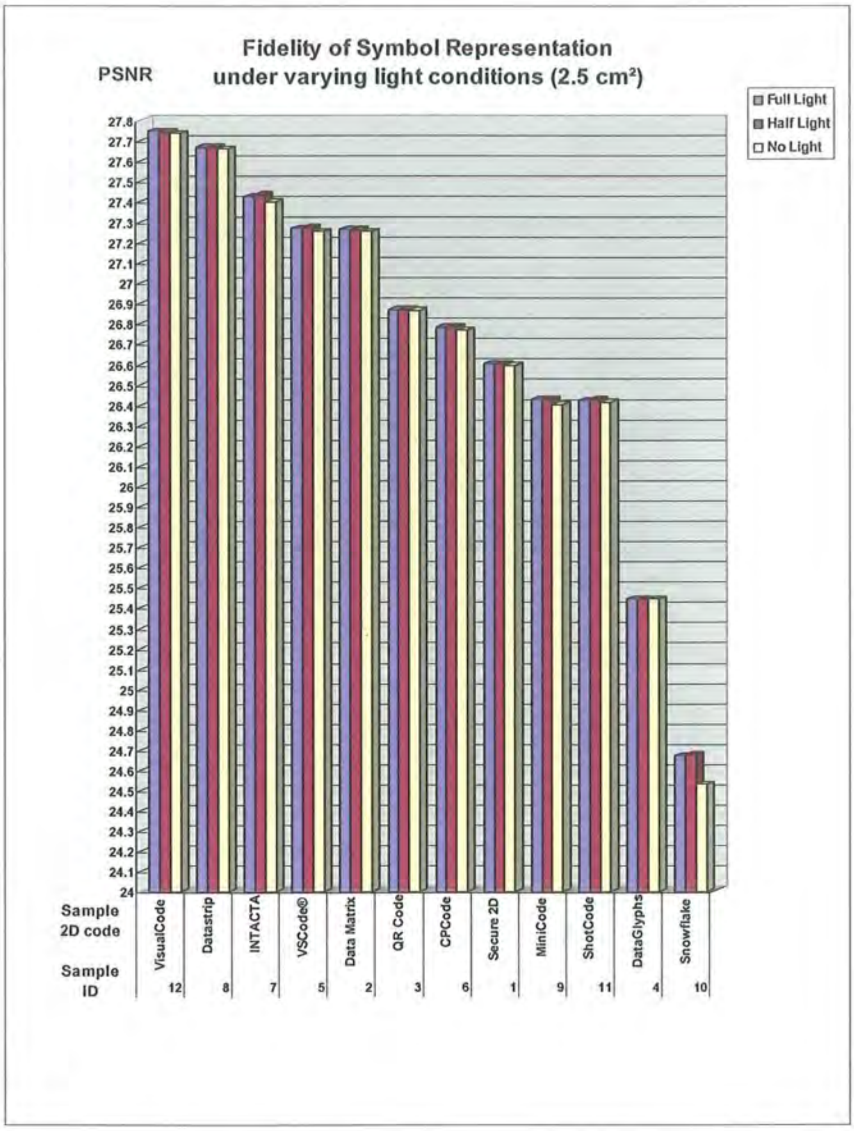


Figure 55: Fidelity of Symbol Representation of S-symbols

In the bar chart in Figure 55, there is a moderate decrease between the first five symbols and the second five symbols, furthermore, between the former group and the latter group. The remarkable point is that there are dramatic drops in mean PSNR value between ShotCode and DataGlyphs symbol, also between DataGlyphs and Snowflake symbol.

The considerable difference in PSNR value within a symbol also should be noted. There is a slight difference in PSNR value between the images of Snowflake code captured under the full light and half light. However, the PSNR value of the image captured with no light is notably low in comparison with the first two.

ii. Mean PSNR Values for L-symbols

Table 14: Mean PSNR Value of L-symbols in Descending Order

No	S-ID	Symbology	PSNR
1	24	VisualCode	28.0532
2	20	Datastrip	27.7513
3	19	INTACTA	27.7317
4	14	Data Matrix	27.2418
5	17	VSCode®	26.9303
6	13	Secure 2D	26.7075
7	18	CPCode	26.6732
8	21	MiniCode	26.4989
9	15	QR Code	26.2810
10	23	ShotCode	26.1572
11	16	DataGlyphs	25.4283
12	22	Snowflake	24.6228

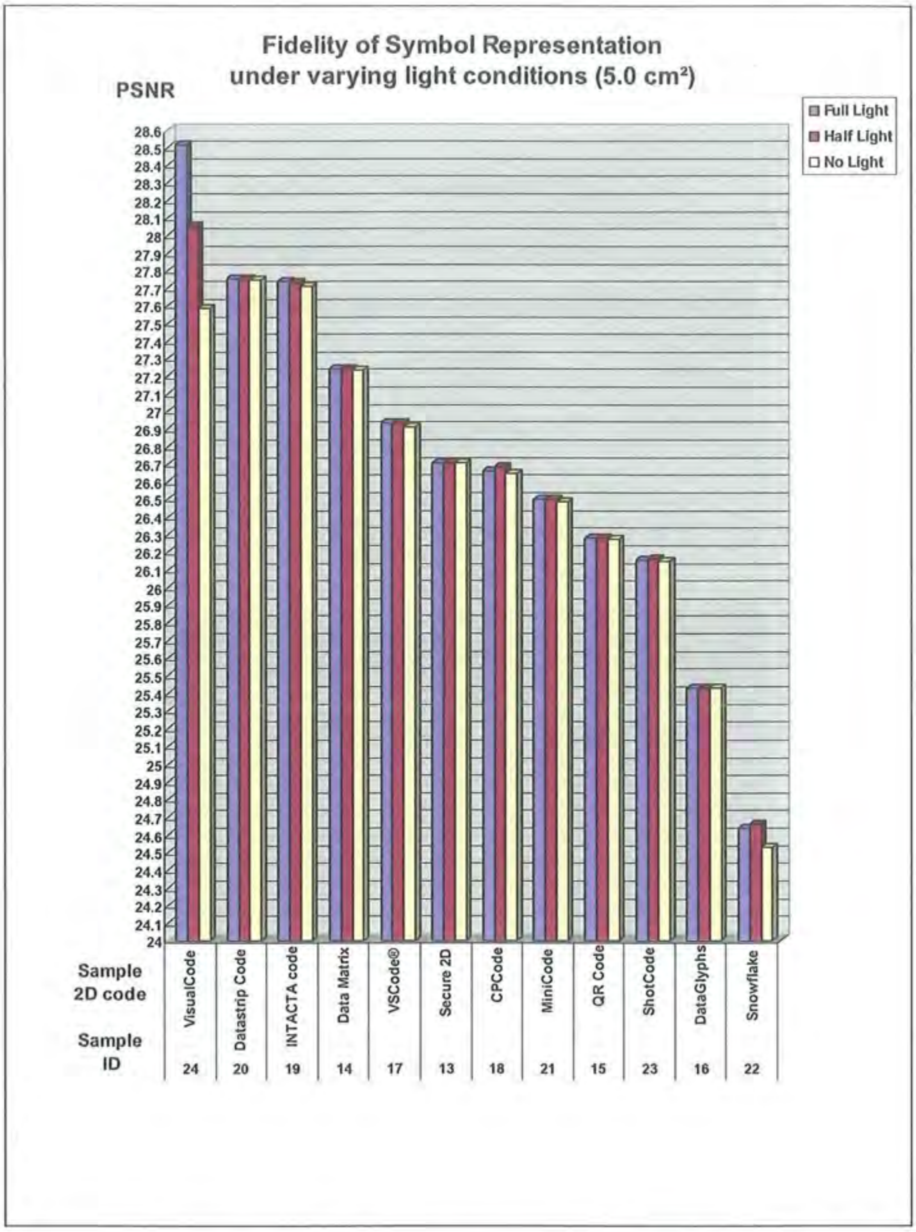


Figure 56: Fidelity of Symbol Representation of L-symbols

Overall, the bar graph demonstrates the similar result that is observed in the result of the first 12 samples (i.e. small sized samples). In fact, order of the top 3 symbols (i.e. Visual Code, Datastrip code, and INTACTA code) and bottom 3 symbols (i.e. ShotCode, DataGlyphs and Snowflakes) are the same as the result of S-symbol examination.

The difference in PSNR value of images of Visual Code captured under the different light conditions is worthy of further investigation. This phenomenon was not observed in the examination of the result of the S-symbols.

There is also difference in PSNR value of Snowflake images taken in the different light conditions; this is anticipated from the S-symbol examination result.

iii. Mean PSNR Values for CR-symbols

Table 15: Mean PSNR Value of CR-symbols in Descending Order

No	S-ID	Symbology	PSNR
1	28	VS Code	27.5864
2	25	Data Matrix	27.3678
3	29	CP Code	27.2599
4	26	QR code	27.0638
5	27	DataGlyphs	25.5553

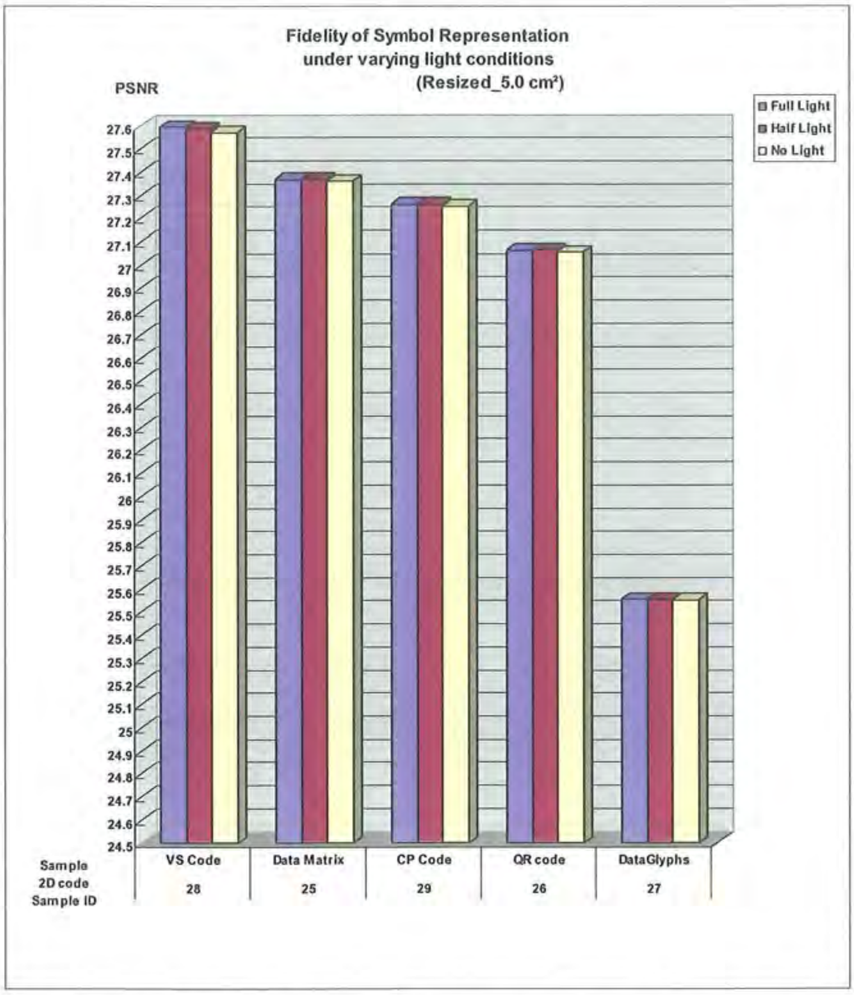


Figure 57: Fidelity of Symbol Representation of CR-symbols

The PSNR values in the table clearly shows that all the CR-symbols obtained the better PSNR values than the same codes in smaller cell size (L-symbols). This result is significant to demonstrate the importance of the symbols that are scalable in size.

II. Sensitivity to the light

It may be possible to say that the symbols with higher PSNR value are more capable of reproducing the intact image, accordingly, are stronger against varying light conditions as well. However, another factor should be considered as far as the symbol strength against the lighting is concerned. In the experiment, there are ordinary lights on the ceiling and these lights had certain effect on capturing the symbol. However, there may be possibility to capture the image in darker places such as a bus stop at night as previously mentioned. To measure the strength of the sample symbols against the light strictly, it is important to see the sensitivity to light of each 2D-barcode. This is achieved by comparing the PSNR values of images of a symbol captured in the different light conditions, namely, full, half, and no light. The difference between the highest PSNR value and the lowest value of each symbol has been calculated and presented in the descending order in the following tables (i.e. Table 16- i , 16- ii , and 16-iii).

Table 16: Difference between the highest and the lowest PSNR Value

i. Difference in PSNR Values (S-symbols)

No	S-ID	Symbology	Difference
1	10	Snowflake	0.1489
2	7	INTACTA	0.0353
3	9	MiniCode	0.0264
4	5	VSCode®	0.0207
5	6	CPCode	0.0181
6	12	VisualCode	0.0135
7	2	Data Matrix	0.0135
8	11	ShotCode	0.0124
9	8	Datastrip	0.0092
10	3	QR Code	0.0073
11	1	Secure 2D	0.0069
12	4	DataGlyphs	0.0014

ii. Difference in PSNR Values (L-symbols)

No	S-ID	Symbology	Difference
1	24	VisualCode	0.9266
2	22	Snowflake	0.1311
3	18	CPCode	0.0363
4	19	INTACTA	0.0262
5	17	VSCode®	0.0230
6	21	MiniCode	0.0160
7	23	ShotCode	0.0138
8	20	Datastrip	0.0095
9	14	Data Matrix	0.0064
10	15	QR Code	0.0057
11	13	Secure 2D	0.0029
12	16	DataGlyphs	0.0001

iii. Difference in PSNR Values (C-symbols)

No	S-ID	Symbolofy	Difference
1	28	VS Code	0.0232
2	26	QR code	0.0100
3	29	CP Code	0.0099
4	25	Data Matrix	0.0094
5	27	DataGlyphs	0.0013

The PSNR values of the image captured with no light were the lowest of all the three different light conditions for all the sample symbols. In addition, the difference in PSNR value between the highest and the lowest of each symbol is remarkable. In contrast, there was no distinctive difference between the highest PSNR value and medium value within the same code. The image captured with full light did not always reproduce the image with the highest PSNR value. For some symbols, the image captured with half lighting gained better outcomes than the ones with full lighting. In such cases, the difference between the PSNR value of the image with half light and with no light was calculated to observe the sensitivity of each code to the light. The chart that shows the sensitivity to the light for each code is provided in Figure 64, 65, and 66 in Appendix 9 (p.171-175).

5.2.3.2 Important Findings

I. Through the experiments, one of the most important findings in the experiments is that the image captured and reproduced with half lighting was better than the images with full lighting. This might be due to the negative effect of the reflection. This may affect the use of flash function of a camera phone when required due to insufficient lighting around the target 2D-barcodes. This also indicates that it is considerably difficult, if not impossible, to capture such 2D-barcodes at night time.

II. Overall the PSNR value of Visual Code, which is specifically invented for mobile phone applications, was the highest for both S-symbols and L-symbols. In contrast, the PSNR values of ShotCode were rather low, the third least of all the sampled barcodes although the symbol is also invented targeting the mobile phone applications.

III. Despite the great outcomes in overall PSNR value, the difference in PSNR value in varying light conditions of large sized Visual Code was the highest of all the symbols tested. It indicates that Visual Code is more likely to be affected by the light condition. Possible reason to explain the phenomenon is the contrast of the black and white bits. As Visual Code is specifically designed to use a built-in camera of mobile phones as an imager, each cell size is considerably large comparing with other 2D-barcodes. It may increase the possibility for each cell to be exposed to more light effect, as a result, absorb it. Overall performance of

Visual Code in both size is highest, thus it should be taken into consideration when selecting a standard 2D-barcode for mobile phone applications.

Figure 58 presents the bar charts that show sensitivity to the light of DataGlyphs code and Visual Code. The images of Visual Code captured by the camera phone are provided in Figure 59.

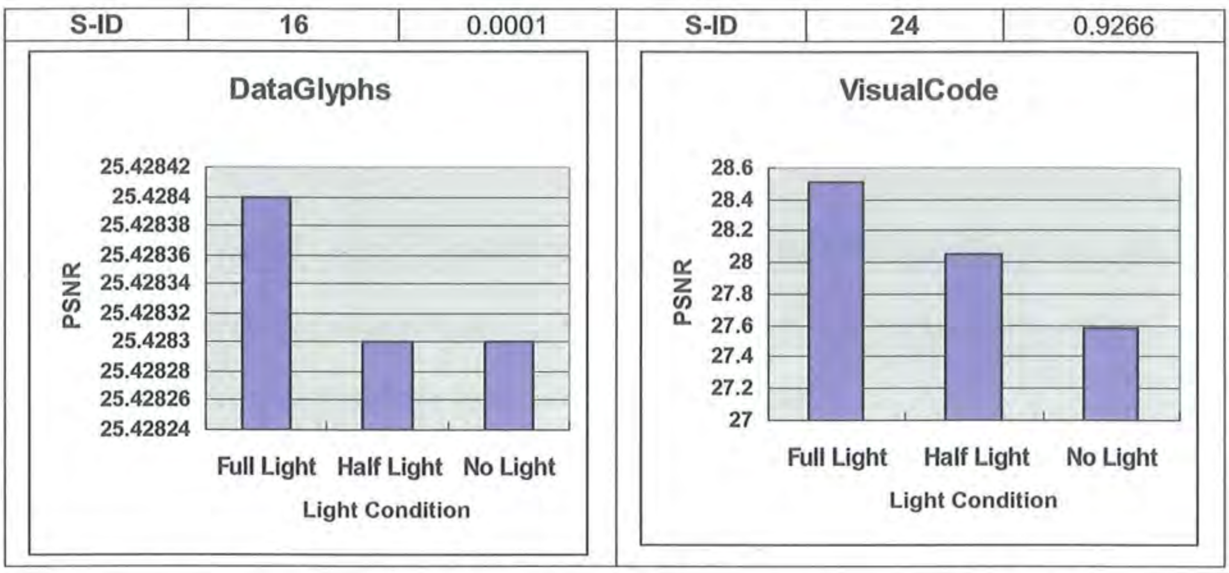


Figure 58: Comparison Visual Codes with DataGlyphs (least sensitive to the light)

(The number in the grey box is the difference between the best PSNR value and the worst PSNR value within the code.)

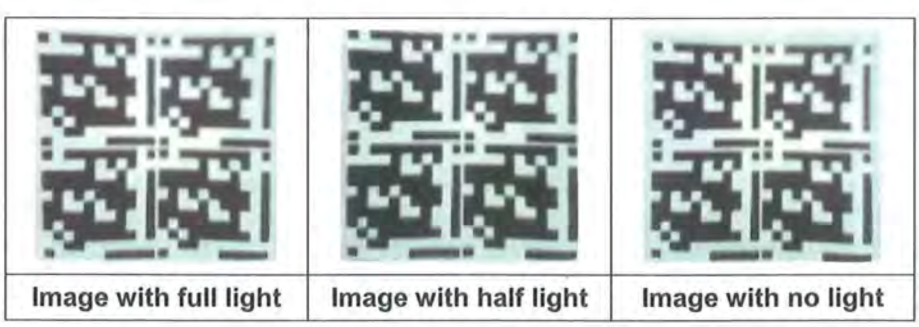


Figure 59: Images of Visual Code under the different light conditions

IV. The graphs of Fidelity of Symbol Representation for both S-symbols and L-symbols show that there is a dramatic drop in PSNR value between ShotCode and DataGlyphs, then between DataGlyphs and Snowflake code. Hence, it is possible to say that DataGlyphs and Snowflake are less likely to be accurately captured by mobile phone built-in cameras unless the cameras are hold in close proximity to the target symbols.

V. Although the overall PSNR value of DataGlyphs was the lowest but one, and showed the weakness against the distance criterion, the symbol demonstrated the strength against lighting sensitivity. DataGlyphs is the least sensitive to the light effect of all the sample symbols. That is, the symbol can be precisely captured regardless of difference in light condition (see, Table 17).

Table 17: PSNR values of Dataglyphs in three different Light Conditions

S-ID	Symbology	PSNR			
			Full Light	Half Light	No Light
4	DataGlyphs	PSNR	25.4447	25.4447	25.4433
16			25.4284	25.4283	25.4283
27			25.5556	25.5556	25.5543

※ The cells are shaded in grey when the PSNR values of a sample are the same

VI. In addition to DataGlyphs, Secure 2D Code and QR Code demonstrated the remarkable strength against light effect (see, Table 18).

Table 18: Symbols with the Least Sensitivity to Light

1. Difference in PSNR Values (S-symbols)

S-ID	Symbology	Difference
3	QR Code	0.0073
1	Secure 2D	0.0069
4	DataGlyphs	0.0014

2. Difference in PSNR Values (L-symbols)

S-ID	Symbology	Difference
15	QR Code	0.0057
13	Secure 2D	0.0029
16	DataGlyphs	0.0001

VII. One of the most incredible findings is that the Datastrip code and INTACTA code gained the second and third highest PSNR value, respectively. The cell sizes of these codes are considerably small and accordingly the density of the symbols is rather high (see, Figure 60).

Datastrip Code	INTACTA Code

Figure 60: Datastrip and INTACTA

5.2.3.3 The Result of the 2nd Assessment

After the careful examination of the experiment result, the cut-off line for each criterion has been drawn:

I. Distance criterion

The top ten symbols out of 12 in each sample group (CR-symbols exclusive) are considered to clear the criteria. This is due to:

- **i.** Significant difference in mean PSNR value between the first 10 symbols and the last 2 symbols
- **ii.** ShotCode, which is specifically designed for mobile phone applications, gained the 10th mean PSNR value of all. Hence, any symbols whose performances were better than ShotCode are regarded as capable of handling distance issue.

II. Light criterion

When the difference between the best and worst PSNR value of a symbol is greater than 0.1, the symbol is considered as not satisfying the light criterion. 0.0353 of INTACTA code for S-symbols and 0.0363 of CP code for L-symbols show the greatest difference between the best and worst PSNR value within a symbol among all the 2D symbols whose result in this examination was less than 0.1. Hence, more than 0.1 differences in PSNR value in a symbol can be seen rather significant. Therefore, it seems reasonable to draw the line at the point of 0.1.

It should be noted, however, that Visual Code is treated as an exception since:

- **i.** Overall performance of Visual Code was highest of all the sample codes in both sizes.

ii. The symbol was designed for mobile phone use considering the reasonable data capacity of the 2D-barcode for mobile applications. The limitation inherent in mobile phones such as low camera resolution and non-floating operation is also considered in designing the code. The change of the symbol physical size might be improper operation for such 2D-barcodes.

III. VGA resolution support criterion

All sample images are captured by a camera phone with VGA (640 × 480). When the quality of the outcomes are sufficient, therefore, it is considered that the symbol satisfy this criterion. The sufficiency was measured by whether or not a symbol can satisfy both distance and light criteria. That is, a 2D-barcode is regarded as satisfactory against the resolution criteria if the PSNR values of images of the 2D-barcode captured by a camera phone with VGA resolution satisfy both distance and light criteria. The result against each criterion is presented in the following table (see, Table 19).

Table 19: 2nd Assessment Result

	Distance	Light	VGA Resolution Support
Secure 2D code	O	O	O
Data Matrix	O	O	O
QR Code	O	O	O
DataGlyphs	×	O	×
VSCode®	O	O	O
CP Code	O	O	O
INTACTA.Code	O	O	O
Datastrip	O	O	O
Mini Code	O	O	O
Snowflake	×	×	×
ShotCode	O	O	O
Visual Code	O	O	O

The complete final result for all the 2nd assessment samples against all the criteria set for this 2D-barcode standardization assessment are provided in Table 35, 36, and 37, in Appendix 10 (p.176).

As the result of the 1st and 2nd assessment, it has been found that the following 2D-barcodes satisfy all the requirements set for the standardization for camera phone applications.

Table 20: 2D-barcodes that meet all the requirements

2D-symbology	No	1	2	3	4	5	6	7	8	9	10
Secure 2D code	8	O	O	O	O	O	O	O	O	O	O
Mobile code	8	O	O	O	O	O	O	O	O	O	O
MS-CODE	8	O	O	O	O	O	O	O	O	O	O
VeriCode®	8	O	O	O	O	O	O	O	O	O	O
VSCode®	8	O	O	O	O	O	O	O	O	O	O
CP Code	8	O	O	O	O	O	O	O	O	O	O

Legend:
No. The number of requirements that each 2D-barcode satisfies.
1. Type: (Stacked: S or Matrix: M)
2. Omni-Directional: (Yes: ○, Otherwise: ×)
3. Error Correction Ability: (Yes: ○, Otherwise: ×)
4. Light Condition: (Legible under widely varying lighting conditions under very low contrast: ○, Otherwise: ×)
5. Distance: Clearly legible at approx. 10 cm away from the code (Yes: ○, Otherwise: ×)
6. Support VGA (640x480 pixels) Resolution (i.e. can be read by a camera with VGA resolution often found in cell phones (Yes: ○, Otherwise: ×)
7. Data Capacity/Density : (High: ○, Low: ×)
8. Security: A code itself is secured by security techniques (e.g. data encryption); exclusive of security provided by additional operations (e.g. Use of authentication sever) (Yes: ○, Otherwise: ×)
9. Multi-Language: (Support any languages other than English as well as English: ○, Otherwise: ×)
10. Domain: (Public: U, Proprietary: R)
11. Additional Feature(s) (Advantageous features of each code if any)

In the final step, comparisons among these 2D-barcodes have been conducted to determine a standard 2D-barcode. Secure 2D Code is different from the other 2D symbols in that it is not scalable in size. The scalability in size has appeared to be a critical feature for a standard 2D-barcode for mobile applications through both the review of the literatures and the experiments. Visual Code, whose cell size is the largest, demonstrated greatest performance in the 2nd assessment. In addition, CR-symbols obtained better results than L-symbols overall.

Any codes that support any language other than English as well as English are regarded as satisfactory against the language criterion. Hence, Mobile code, MS-CODE, which are derivation of QR Code, presumably support only a few different languages (i.e. English, Japanese, and Chinese) clear the multi-language criterion. On the other hand, all other 2D-barcodes that satisfy all the criteria truly support multi-languages.

Mobile code, MS-CODE, VeriCode®, and VSCode® have been utilized for camera phone applications while Secure 2D-barcode and CP Code have not.

VeriCode®, VSCode®, and CP Code are products from the same or the associated companies. Accordingly, there are a lot in common in features among the three codes. However, VSCode® is superior to the other two codes in its data capacity, which is believed to be the greatest among all the 2D-barcodes (VERITEC, Inc., n.d.) (Veritec Iconix Ventures Inc., n.d.). Nevertheless, a larger space is not required for the code placement since VSCode® is adjustable in shape and scalable in size. In addition, the code can be divided into smaller codes. As previously mentioned, the data capacity that a built-in camera of mobile phones can handle is limited due to the low quality of such cameras as imagers. Accordingly, the data capacity is not the first priority for the standard 2D-barcode selection. However, if a symbol has higher data capacity in less space while keeping the cell size legible, it is seen advantageous. The Figure 61 shows the differences in size among 3 2D-barcodes. DataGlyphs symbol needs much larger space to encode the same amount of data. This means that the density becomes higher to accommodate a given data in a given space, which may prevent the code from being successfully decoded. Table 21 and 22 respectively show the difference in density and minimum symbol size between 3 2D-barcodes utilized for camera phone application.

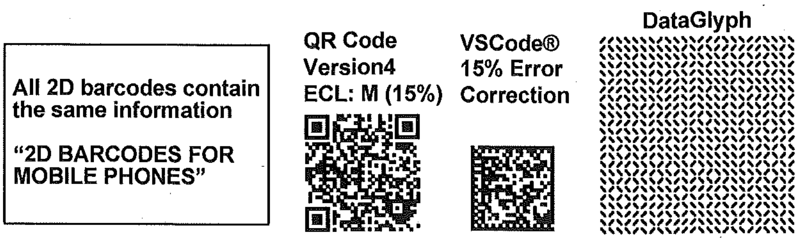


Figure 61: Difference in Size of 2D-barcodes

Table 21: Symbol Density Comparison

Symbology	QR Code	VeriCode	DataMatrix
(Number of characters /1cm²)	Approx. 75 characters (Alphanumeric)	Approx. 100 characters (Alphanumeric)	Approx. 120 characters (Alphanumeric)
Cell size	0.25mm	0.25mm	0.25mm

Table 22: Minimum Symbol Size Comparison

Symbols	Minimum Cells	Symbol size	Data capacity
DataMatrix	10×10	2.5×2.5+0.5mm(QZ)※	6 rows×6 columns
VeriCode	10×10	2.5×2.5+4.0mm(QZ)	4 rows×4 columns
QR Code	21×21	5.3×5.3+4.0mm(QZ)	40 rows×40 columns

Note: Symbol size are calculated providing each cell size is 0.25 mm, ※QZ indicates quiet zone

Source: Small size, Error Correction Capability, and Reading speed. (AINIX Corporation., 2002). Retrieved October, 28, 2005, from http://www.ainix.co.jp/barcode/c_04_02.shtml

3 position detection pattern of QR Code enables the symbol to be read in ultra-speed. However, it could have negative effect when the reading speed it not at a premium as they reduces the size of data field.

Security feature is also important for a standard 2D-barcode since there is a growing popularity in the use of mobile phones for payment. VeriCode®, VSCode®, CP Code, and Secure 2D Code that are capable of encoding ciphered data into the codes themselves is viewed favourably in this respect.

Considering all the factors and/or criteria described above, VSCode® may have the greatest potential to be selected as standard. In addition to meeting all the requirements set in our assessment, VSCode® can also provide scalability and flexibility that can well respond to the demand of a wide range of camera phone applications; not only those currently used in the market but also applications in the future where greater data capacity may be required. One thing we should also bear in mind is that the accessibility of the code as VSCode® is patented by Veritec Inc.

5.3 Tentative Conclusion

Nine criteria have been established to select a best 2D-barcode for camera phone applications considering the capability and operating limitations of current camera phones and the existing 2D-barcodes. However, mobile technology is still in progress and it is important that the standardized 2D-barcode not only satisfies the criteria set, but also have features that can meet the demand of applications in the future. Hence, from this study, VSCode® is considered to work best as a potential candidate for a standard 2D-barcode for camera phone applications.

The lack of encoder/decoder prevented the study from examining each sample symbol with unquestionable accuracy. Hence, it may be too early to reach a definite conclusion. However, it is believed that this shortcoming was well covered by the use of benchmark tool in image analysis written in MATLAB.

5.4 Limitation of the Study

There are more than 30 barcodes that are publicly accessible and basically the different 2D-barcode use the different encoder/decoder. In the study, encoders were not available for all the sample codes. The images provided in the publicly accessible information sources such as web sites were used as samples for some 2D-barcodes whose encoders were inaccessible in the experiments. The size of such sample codes may be incorrect and it may prevent them from being precisely tested.

Instead of using the decoder required for each 2D-barcode, the examination of the 2D-barcodes in the second phase assessment was administered by using benchmark tool in image analysis written in the scientific language of MATLAB to assess the legibility of a symbol under certain settings. The author is aware that the examination of 2D-barcodes in such a way is not as reliable as the examination with the use of encoder/decoder relevant to each 2D-barcode. However, the cost to purchase all the available encoders/decoders by far exceeds the budget for the study. Moreover, it is more likely that no decoder that can be installed into mobile phones exists for certain 2D-barcodes since they were not designed for the use for the camera phone applications. This further proves the inconvenience of the lack of a standard 2D-barcode, and thus nearly no interoperability between the devices where different 2D-barcode and the barcode specific decoder are utilized.

By the use of a standard image analysis technique, namely the analysis of image PSNR values using MATLAB, it is believed that the author has sufficiently compensated for the shortcoming of this study.

5.5 Summary

The assessment consists of two phases. In the first assessment, all the existing 2D-barcodes were qualitatively examined in terms of criteria established (i.e. Omni-Directional reading, Error Correction Ability, Light Condition, Distance, VGA (640 × 480 pixels) Resolution Support, Data Capacity/Density, Security, and Multi-Language) to select a best 2D-barcode as a potential standard. The second phase assessment involved the quantitative experiments using the sample 2D-barcodes that met equal to or more than 4 criteria in the first phase assessment. The second assessment was conducted to further examine the 2D-barcodes that have potential to be chosen as a standard 2D-barcode in terms of 3 criteria, namely, light condition, distance, and VGA resolution support.

As a result, it has appeared that the 6 2D-barcodes satisfied all the requirements set for the standardization selection. These 2D-barcodes are Secure 2D Code, Mobile code, MS-Code, VeriCode®, VSCode®, and CP Code. Furthermore, this study has found that VSCode® has a great potential to be selected as a standard 2D-barcode as it well met the requirements of camera phone applications in current use and probably future applications.

On the other hand, this study has certain limitations. One of the problems was the lack of availability of encoders/decoders. This prevented the study from assessing all the sample 2D-barcodes accurately. It make it impossible to test the first read rate of each 2D symbols, which is one of the important elements to know in regard to the capability of each code. Such a limitation indicates the need for further study in this field.

6 Further Study

6.1 Current Findings

Through the study, important factors have revealed, which should be considered to select a standard 2D-barcode:

I. Flexibility

The standard 2D-barcode should be scalable in size so that the symbol can be used in any camera phones, ranging from those with low resolution to the latest mega-pixel camera phones. The 2D-barcodes that have structure append function are also desirable as the code can be divided into smaller pieces, which leads to more application available for more camera phones.

II. Light effect

In the second experiment, the PSNR value of image captured with half light than full light was better for some sample symbols. This may indicate the negative effect of the reflection when the amount of the light exceeds the amount which should be required. Such impact should be carefully examined when developing applications that may be used at night and thus required additional light source.

The above factors are two of the most important findings of this study. However, there is another important factor that has not been examined in the study due to the lack of decoders for all the sampled 2D-barcodes. That element is the first read rate, which indicates what percentage a 2D-barcode can be successfully read at the first attempt. This measure can be used to gauge the reliability of each 2D-barcode.

It has some time since Semacode was introduced into the world and it is reasonable to believe that the operation of Semacode application is reliable. However, Scott, Sharp, Madhavapeddy, & Upton (2005) state that Semacode is unstable due to the unreliability of the reader implementation. Scott et al. (2005) claim the difficulty of clicking on Semacodes is due to a lack of real-time feedback. Scott et al. also report that they experienced more than 30 % of decoding error using Semacode.

According to Barnes et al. (1999) acceptable first read rate is a problem not only of 2D-barcodes utilized in mobile applications but also ordinary 2D-barcodes in industrial use. Nevertheless, no research has been done to date to assess this first read rate issue.

6.2 Future Work

As described in the section 6.1, it is believed that the outcome of the research to assess the first read rates should be beneficial not only for the development of camera phone applications, but also for the development or improvement of 2D-barcodes in industrial use.

There is another issue that has hardly been deeply investigated. That is the development of a 2D-barcode that uses colour pattern as a code feature. There is a trend that researchers take it for granted that the use of colour symbol is:

i. more expensive both computationally and economically;

ii. inconvenient as monochrome printers are more widely available than colour printers; and

iii. both difficult and unreliable since the lighting conditions considerably affect on colour values and colour sensitivity of CCD cameras are also different.

It is more likely that the study on a 2D-barcode that uses colour pattern as a code feature will include the study of lighting effect on 2D symbols (i.e. sensitivity to the light of each 2D-barcode).

Consequently, the studies that are of worthy challenge as future works are:

i. the study on the first read rate of 2D-barcodes; and

ii. the study of a 2D-barcode that uses colour pattern as a code feature.

7 Glossary

Augmented Reality
The idea that an observer's experience of an environment can be augmented with computer generated information. Usually this refers to a system in which computer graphics are overlaid onto a live video picture or projected onto a transparent screen as in a head-up display.

Bluetooth
A short-range radio technology aimed at simplifying communications among Internet devices and between devices and the Internet. It also aims to simplify data synchronization between Internet devices and other computers.

CCD
Short for charge-coupled device, an instrument whose semiconductors are connected so that the output of one serves as the input of the next. Digital cameras, video cameras, and optical scanners all use CCD arrays.

Convolutional-code error-correction
A convolutional code is a type of error-correcting code in which (a) each m-bit information symbol (each m-bit string) to be encoded is transformed into an n-bit symbol, where m/n is the code rate (n >= m) and (b) the transformation is a function of the last k information symbols, where k is the constraint length of the code.

CORBA
Common Object Request Broker Architecture, an architecture that enables pieces of programs, called objects, to communicate with one another regardless of what programming language they were written in or what operating system they're running on. CORBA was developed by an industry consortium known as the Object Management Group (OMG).

CPU
Central processing unit (CPU) is the part of a computer that interprets and carries out the instructions contained in the software. The "brain" of the computer. This is the microprocessor that actually performs the computations in machine language. Some people use the term "CPU" to refer to the entire component (i.e. the computer that includes the central processing unit.

Floating Point Unit (FPU)
A floating-point unit is a part of a CPU specially designed to carry out operations on floating point numbers. Typical operations are floating point arithmetic (such as addition and multiplication), but some systems may be capable of performing exponential or trigonometric calculations as well (such as square roots or cosines).
Not all CPUs have a dedicated FPU. In the absence of an FPU, the CPU may use a microcode program to emulate a FPUs function using an arithmetic and logical unit (ALU), which saves the added

hardware cost of an FPU but is significantly slower. In some computer architectures, floating point operations are handled completely separate from integer operations, with dedicated floating point registers and independent clocking schemes. Floating point addition and multiplication operations are typically pipelined, but more complicated operations, like division, may not be, and some systems may even have a dedicated floating point divider circuit.

ISO 646

ISO 646 is an ISO standard that specifies a 7 bit character code from which several national standards are derived, the best known of which is ASCII. Since the portion of ISO 646 shared by all countries specified only the letters used in the English alphabet, other countries using the Latin alphabet with extensions needed to create national variants of ISO 646 to be able to use their native languages. Since universal acceptance of the 8 bit byte did not exist at that time, the national characters had to be made fit within the constraints of 7 bits, meaning that some characters that appear in ASCII do not appear in other national variants of ISO 646.

Japanese Industrial Standard (JIS)

In computing, JIS encoding refers to several Japanese Industrial Standards for encoding the Japanese language. Strictly speaking, the term means either:

A set of standard character sets for Japanese, notably:

- JIS X 0201, the Japanese version of ISO 646 (ASCII) containing the base 7-bit ASCII characters (with some modifications) and 64 half-width katakana characters.
- JIS X 0208, the most common kanji character set containing 6,879 kanji
- JIS X 0202 (also known as ISO-2022-JP), a set of encoding mechanisms for sending JIS

There is also the Shift_JIS encoding, which adds the kanji, full-width hiragana and full-width katakana from JIS X 0208 in a compatible way to JIS X 0201. Shift_JIS is perhaps the most widely used encoding in Japan.

Light Emitting Diode (LED)

Abbreviation of light emitting diode, an electronic device that lights up when electricity is passed through it. LEDs are usually red. They are good for displaying images because they can be relatively small, and they do not burn out. However, they require more power than LCDs

Mean Squared Error (MSE)

Mean Squared Error (MSE) is a statistical measure of error, used to determine quality of compressed images. Mathematically equivalent to Peak Signal to Noise Rate (PSNR).

Pulse Coded Modulation (PCM)	Transmission of analog information in digital form through sampling and encoding the samples with a fixed number of bits.
Peak Signal-to-Noise Ratio (PSNR)	The phrase peak signal-to-noise ratio, often abbreviated PSNR, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale.
Public-key Encryption	A cryptographic system that uses two keys -- a public key known to everyone and a private or secret key known only to the recipient of the message. When Bob wants to send a secure message to Alice, he uses Alice's public key to encrypt the message. Alice then uses her private key to decrypt it. An important element to the public key system is that the public and private keys are related in such a way that only the public key can be used to encrypt messages and only the corresponding private key can be used to decrypt them.
Reed-Solomon error correction	Reed-Solomon error correction is a coding scheme which works by first constructing a polynomial from the data symbols to be transmitted and then sending an over-sampled plot of the polynomial instead of the original symbols themselves. Because of the redundant information contained in the over-sampled data, it is possible to reconstruct the original polynomial and thus the data symbols even in the face of transmission errors, up to a certain degree of error.
Sentient Computing (SC)	Sentient Computing is the approach by Ipiña1, Mendonça2, & Hopper (2002) to make Ubiquitous Computing a reality. It creates perceptive living spaces [2] where user's activities are enhanced by software services provided by devices embedded in the environment.
Ubiquitous (pervasive) computing	Ubiquitous computing integrates computation into the environment, rather than having computers which are distinct objects. Another term for ubiquitous computing is pervasive computing.
Unicode	Unicode is an international standard whose goal is to provide the means by which text of all forms and languages can be encoded for use by computers.
Universal Product Code (UPC)	Universal Product Code is the standard bar code symbol for retail packaging in the United States.

VGA Abbreviation of video graphics array, a graphics display system for PCs developed by IBM. VGA has become one of the de facto standards for PCs. In text mode, VGA systems provide a resolution of 720 by 400 pixels. In graphics mode, the resolution is either 640 by 480 (with 16 colours) or 320 by 200 (with 256 colours). The total palette of colours is 262,144.

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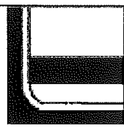
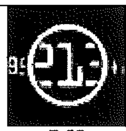
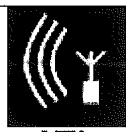
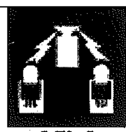
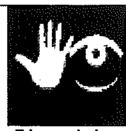
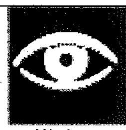
10 Appendices

Appendix 1: Types of AI technologies

	Type	Image	Description
1.	**Bar Code**	Bar Code	Dark rectangular bars and white rectangular spaces are alternated where the widths of individual rectangles are varied to code information.
2.	**Magnetic Stripe**	 MRC	Magnetic cards, pre-paid cards, hybrid IC -magnetic cards, etc.
3.	**OCR**	 OCR	Optical Character Recognition
4.	**RF/ID (Radio Frequency Identification)**	 RFID	Identification device for radio frequency recording of data on card- or tag-shaped media and for communications through an antenna.
5.	**RF/DC (Radio Frequency Data Communications)**	 RFDC	Generic term for communications systems involving two-way communications between a host computer and portable terminals for collecting and transmitting/receiving data.
6.	**Smart Card**		Credit card with built-in CPU and memory. Has superior security function and communications function for data recording and retrieval.
7.	**Optical Card**		Credit-card size ROM with optically recorded/stored large amount of data.
8.	**Memory Button (Touch Memory)**		Essentially functions the same way as RF/ID does. Tag or card shaped, and has a stainless steel cover. Data is transferred through contact with this cover.
9.	**Biometric Identification**	 Biometrics	Identification by biometric characteristics such as finger prints and retinal patterns.
10.	**Machine Vision**	 Vision	Image processing by computer.
11.	**Voice Recognition**	 Voice	Converts human voice into electric signals and inputs them into computer.
12.	**EDI (Electronic Data Interchange)**		Online transmission/receipt of all transaction data including customer name, product name and price information to facilitate processing steps.

Extracted from JAISA website, http://www.jaisa.or.jp/english/Technologies/index.html

Appendix 2: Current Uses of Barcode Technology

Table 23: Current Use of Barcode Technology

Category	Purpose / Objects of Barcode Use
Commerce	Anti-theft, Publications. Books (Bookland, U.P.C.※, Price code), Magazines (U.P.C., Supplementary), Library (Inventory, Shelf, Checkout), Video stores/music, Catalogues, Shopping cart (Check out), Electronic shelf (Tags), Turnpikes, Highway control, Banking (ATM, Money recodes, Cheques and documents, Money and inventory)
Industry	Quality control (Verification of correct parts, traceability of components, finished assembly), Materials (Management, Material flow, Stock control, Inventory, Tracking material), Production control, Control machinery, Robotics, Install Components, Photographic, Plant operations, Electronic (Components and production), Paper production, MRP (Material resource planning/JIT※ and similar systems), Advance shipping notice, Electronic proof of shipping, Electronic proof of receipt, Automotive bodies (Paint, Parts control and others), Computer boards and many production operations, Light industry and job shops (engineering, design, documents, pre-production models and parts tools)
Retail	Checkout, Ordering, Receipt, Damaged, bad stock, Inventory, Control, Self-checkout (Research and development), Purchasing
Distribution	Packaging (Primary, Secondary, Shipping container, Unit loads, Others). Trucks and rail (Cars/wagons, Barcodes or transducer sensors), Package delivery (Continuous control, Customer satisfaction, Hub operation, Detailed information to ensure overnight delivery), Postal codes, Conveyors, Warehousing, Truck loading, Vehicle location, Material movement, Total data information
Medical	Patient history (trabs-portable medical record), Smart card (Matrix, stacked code), Equipment, Patients, Staff authorization, Pharmaceuticals, Unit does, Other patient-used items to be charged, Human blood, Other materials with life/death effects, Controlling shelf life, Organization with standards, HIBCC (Health Industry Business Communications Council), NWDA (National Wholesale Drug Association), European medical organizations
Documents	Forms, Sales/marketing, Order forms, Shipping and receiving, Accounting, Payroll, Scheduling, Holiday/vacation
Other	Traffic and sensors, Person tracking and location, Vehicle tracking and location, Transponders, Security, Card (eye print, voice, other), Voice recognition, Research and development, Tracking items and tests, Traceability, Radio and TV cassettes, Police inspections, Emission inspections, Kidnapped/lost children, Mount Everest equipment control, Sports (long distance runners, Olympics: Access/security), Bees, fish and other animals

Appendix 3: The Maximum QR Code Data Capacity for each version

Table 24: The Maximum QR Code Data Capacity for Version 1 to 10

Version	Modules	ECC Level	Data bits	Numeric	Alphanumeric	Binary	Kanji
1	21x21	L	152	41	25	17	10
		M	128	34	20	14	8
		Q	104	27	16	11	7
		H	72	17	10	7	4
2	25x25	L	272	77	47	32	20
		M	224	63	38	26	16
		Q	176	48	29	20	12
		H	128	34	20	14	8
3	29x29	L	440	127	77	53	32
		M	352	101	61	42	26
		Q	272	77	47	32	20
		H	208	58	35	24	15
4	33x33	L	640	187	114	78	48
		M	512	149	90	62	38
		Q	384	111	67	46	28
		H	288	82	50	34	21
5	37x37	L	864	255	154	106	65
		M	688	202	122	84	52
		Q	496	144	87	60	37
		H	368	106	64	44	27
6	41x41	L	1,088	322	195	134	82
		M	864	255	154	106	65
		Q	608	178	108	74	45
		H	480	139	84	58	36
7	45x45	L	1,248	370	224	154	95
		M	992	293	178	122	75
		Q	704	207	125	86	53
		H	528	154	93	64	39
8	49x49	L	1,552	461	279	192	118
		M	1,232	365	221	152	93
		Q	880	259	157	108	66
		H	688	202	122	84	52
9	53x53	L	1,856	552	335	230	141
		M	1,456	432	262	180	111
		Q	1,056	312	189	130	80
		H	800	235	143	98	60
10	57x57	L	2,192	652	395	271	167
		M	1,728	513	311	213	131
		Q	1,232	364	221	151	93
		H	976	288	174	119	74

Table 25: The Maximum QR Code Data Capacity for Version 11 to 20

Version	Modules	ECC Level	Data bits	Numeric	Alphanumeric	Binary	Kanji
11	61x61	L	2,592	772	468	321	198
		M	2,032	604	366	251	155
		Q	1,440	427	259	177	109
		H	1,120	331	200	137	85
12	65x65	L	2,960	883	535	367	226
		M	2,320	691	419	287	177
		Q	1,648	489	296	203	125
		H	1,264	374	227	155	96
13	69x69	L	3,424	1,022	619	425	262
		M	2,672	796	483	331	204
		Q	1,952	580	352	241	149
		H	1,440	427	259	177	109
14	73x73	L	3,688	1,101	667	458	282
		M	2,920	871	528	362	223
		Q	2,088	621	376	258	159
		H	1,576	468	283	194	120
15	77x77	L	4,184	1,250	758	520	320
		M	3,320	991	600	412	254
		Q	2,360	703	426	292	180
		H	1,784	530	321	220	136
16	81x81	L	4,712	1,408	854	586	361
		M	3,624	1,082	656	450	277
		Q	2,600	775	470	322	198
		H	2,024	602	365	250	154
17	85x85	L	5,176	1,548	938	644	397
		M	4,056	1,212	734	504	310
		Q	2,936	876	531	364	224
		H	2,264	674	408	280	173
18	89x89	L	5,768	1,725	1,046	718	442
		M	4,504	1,346	816	560	345
		Q	3,176	948	574	394	243
		H	2,504	746	452	310	191
19	93x93	L	6,360	1,903	1,153	792	488
		M	5,016	1,500	909	624	384
		Q	3,560	1,063	644	442	272
		H	2,728	813	493	338	208
20	97x97	L	6,888	2,061	1,249	858	528
		M	5,352	1,600	970	666	410
		Q	3,880	1,159	702	482	297
		H	3,080	919	557	382	235

Table 26: The Maximum QR Code Data Capacity for Version 21 to 30

Version	Modules	ECC Level	Data bits	Numeric	Alphanumeric	Binary	Kanji
21	101x101	L	7,456	2,232	1,352	929	572
		M	5,712	1,708	1,035	711	438
		Q	4,096	1,224	742	509	314
		H	3,248	969	587	403	248
22	105x105	L	8,048	2,409	1,460	1,003	618
		M	6,256	1,872	1,134	779	480
		Q	4,544	1,358	823	565	348
		H	3,536	1,056	640	439	270
23	109x109	L	8,752	2,620	1,588	1,091	672
		M	6,880	2,059	1,248	857	528
		Q	4,912	1,468	890	611	376
		H	3,712	1,108	672	461	284
24	113x113	L	9,392	2,812	1,704	1,171	721
		M	7,312	2,188	1,326	911	561
		Q	5,312	1,588	963	661	407
		H	4,112	1,228	744	511	315
25	117x117	L	10,208	3,057	1,853	1,273	784
		M	8,000	2,395	1,451	997	614
		Q	5,744	1,718	1,041	715	440
		H	4,304	1,286	779	535	330
26	121x121	L	10,960	3,283	1,990	1,367	842
		M	8,496	2,544	1,542	1,059	652
		Q	6,032	1,804	1,094	751	462
		H	4,768	1,425	864	593	365
27	125x125	L	11,744	3,514	2,132	1,465	902
		M	9,024	2,701	1,637	1,125	692
		Q	6,464	1,933	1,172	805	496
		H	5,024	1,501	910	625	385
28	129x129	L	12,248	3,669	2,223	1,528	940
		M	9,544	2,857	1,732	1,190	732
		Q	6,968	2,085	1,263	868	534
		H	5,288	1,581	958	658	405
29	133x133	L	13,048	3,909	2,369	1,628	1,002
		M	10,136	3,035	1,839	1,264	778
		Q	7,288	2,181	1,322	908	559
		H	5,608	1,677	1,016	698	430
30	137x137	L	13,880	4,158	2,520	1,732	1,066
		M	10,984	3,289	1,994	1,370	843
		Q	7,880	2,358	1,429	982	604
		H	5,960	1,782	1,080	742	457

Table 27: The Maximum QR Code Data Capacity for Version 31 to 40

Version	Modules	ECC Level	Data bits	Numeric	Alphanumeric	Binary	Kanji
31	141x141	L	14,744	4,417	2,677	1,840	1132
		M	11,640	3,486	2,113	1,452	894
		Q	8,264	2,473	1,499	1,030	634
		H	6,344	1,897	1,150	790	486
32	145x145	L	15,640	4,686	2,840	1,952	1,201
		M	12,328	3,693	2,238	1,538	947
		Q	8,920	2,670	1,618	1,112	684
		H	6,760	2,022	1,226	842	518
33	149x149	L	16,568	4,965	3,009	2,068	1,273
		M	13,048	3,909	2,369	1,628	1,002
		Q	9,368	2,805	1,700	1,168	719
		H	7,208	2,157	1,307	898	553
34	153x153	L	17,528	5,253	3,183	2,188	1,347
		M	13,800	4,134	2,506	1,722	1,060
		Q	9,848	2,949	1,787	1,228	756
		H	7,688	2,301	1,394	958	590
35	157x157	L	18,448	5,529	3,351	2,303	1,417
		M	14,496	4,343	2,632	1,809	1,113
		Q	10,288	3,081	1,867	1,283	790
		H	7,888	2,361	1,431	983	605
36	161x161	L	19,472	5,836	3,537	2,431	1,496
		M	15,312	4,588	2,780	1,911	1,176
		Q	10,832	3,244	1,966	1,351	832
		H	8,432	2,524	1,530	1,051	647
37	165x165	L	20,528	6,153	3,729	2,563	1,577
		M	15,936	4,775	2,894	1,989	1,224
		Q	11,408	3,417	2,071	1,423	876
		H	8,768	2,625	1,591	1,093	673
38	169x169	L	21,616	6,479	3,927	2,699	1,661
		M	16,816	5,039	3,054	2,099	1,292
		Q	12,016	3,599	2,181	1,499	923
		H	9,136	2,735	1,658	1,139	701
39	173x173	L	22,496	6,743	4,087	2,809	1,729
		M	17,728	5,313	3,220	2,213	1,362
		Q	12,656	3,791	2,298	1,579	972
		H	9,776	2,927	1,774	1,219	750
40	177x177	L	23,648	7,089	4,296	2,953	1,817
		M	18,672	5,596	3,391	2,331	1,435
		Q	13,328	3,993	2,420	1,663	1,024
		H	10,208	3,057	1,852	1,273	784

Appendix 4: The Maximum Data Capacity of Data Matris for each size

Table 28: Data Matrix Symbol Size and Data Capacity – Square Symbols

Symbol Size		Data Region		Codeword No.		Maximum Data Capacity			Error ※1 Correction Capability	EC/ Data+EC
Row	Column	Size	Block No.	Data	EC	N	A	B	[%]	[%]
10	10	8×8	1	3	5	6	3	1	25	62.5
12	12	10×10	1	5	7	10	6	3	25	58.3
14	14	12×12	1	8	10	16	10	6	28 - 39	55.6
16	16	14×14	1	12	12	24	16	10	25 - 38	50.0
18	18	16×16	1	18	14	36	25	16	22 - 34	43.8
20	20	18×18	1	22	18	44	31	20	23 - 38	45.0
22	22	20×20	1	30	20	60	43	28	20 - 34	40.0
24	24	22×22	1	36	24	72	52	34	20 - 35	40.0
26	26	24×24	1	44	28	88	64	42	19 - 35	38.9
32	32	14×14	4	62	36	124	91	60	18 - 34	36.7
36	36	16×16	4	86	42	172	127	84	16 - 30	32.8
40	40	18×18	4	114	48	228	169	112	15 - 28	29.6
44	44	20×20	4	144	56	288	214	142	14 - 27	28.0
48	48	22×22	4	174	68	348	259	172	14 - 27	28.1
52	52	24×24	4	204	84	408	304	202	15 - 27	29.2
64	64	14×14	16	280	112	560	418	278	14 - 27	28.6
72	72	16×16	16	368	144	736	550	366	14 - 26	28.1
80	80	18×18	16	456	192	912	682	454	15 - 28	29.6
88	88	20×20	16	576	224	1152	862	574	14 - 27	28.0
96	96	22×22	16	696	272	1392	1042	694	14 - 27	28.1
104	104	24×24	16	816	336	1632	1222	814	15 - 28	29.2
120	120	18×18	36	1050	408	2100	1573	1048	14 - 27	28.0
132	132	20×20	36	1304	496	2608	1954	1302	14 - 26	27.6
144	144	22×22	36	1558	620	3116	2335	1556	14 - 27	28.5

N: Numeric, A: Alphanumeric, B: 8bit Byte

※1: Data restoration rate for total codewords (codeword is a unit that constructs the data area). Data restoration rate for words that could not be read and those that are wrongly read is different. The ratio for the former is lower than the latter; hence the whole range is presented in the table (e.g. 28 – 39).

Table 29: Data Matrix Symbol Size and Data Capacity – Rectangular Symbols

Symbol Size		Data Region		Codeword No.		Maximum Data Capacity			EC/ Data+EC
Row	Column	Size	Block No.	Data	EC	N	A	B	[%]
8	18	6×16	1	5	7	10	6	3	58.3
8	32	6×14	2	10	11	20	13	8	52.4
12	26	10×24	1	16	14	32	22	14	46.7
12	36	10×16	2	22	18	44	31	20	45.0
16	36	14×16	2	32	24	64	46	30	42.9
16	48	14×22	2	49	28	98	72	47	36.4

Appendix 5: The result of the 1st Assessment.

Table 30: The Result of the 1st Assessment.

2D-Symbology	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
3-DI	M									R	
ArrarTag	M			O	O		O			R	
Aztec Code	M	O	O				O		X	U	Scalable in size
Small Aztec Code	M	O	O				O		X	U	
Codablock	S	X					O		X		Scalable in size
Codablock F	S	X					O		X		Scalable in size
Code 1	M	X	O				O		X	U	Scalable in size
Code 16K	S	X					O		X		
Code 49	S	X					O		X	U	
CP Code	M	O	O				O	O	O	R	
DataGlyphs	M	O	O	O			O	O	O	R	
Data Matrix	M	O	O	O	O	O	O		O	U	
Datastrip Code	S	X	O		X		O	O	O	R	Scalable in size
Dot Code A (Philips Dot Code)	M		O				O				
hueCode	N/A	△*	O				O		O	R	
INTACTA.CODE	M		O			O	O	O	O	R	Scalable in size. Data compression.
MaxiCode (UPSCode)	M	O	O			X	X			U	Requires higher resolution printer.
MiniCode	M	O	O			O	O			R	Scalable in resolution.
Mobile code	M	O	O			O	O	O	O	U	Scalable in size.
MS-CODE	M	O	O			O	O	O	O	U	Scalable in size.
PDF 417	S	X	O				O	O		U	
Micro PDF417	S	X	O				O	O		U	
QR Code	M	O	O			O	O		O	U	Scalable in size. Can be divided.
Micro QR Code	M	O	O			O	X		O	U	Scalable in size.
Secure 2D barcode	M	O	O	O		O	O	O	O	N/A	2 security layers. Data hiding feature.
Semacode	M	O	O	O	O	O	O			U	Scalable in size.
SmartCode							O			R	
Snowflake Code	M	O	O	O			O			R	
ShotCode (SpotCode)	M	O				O					Works irrespective of lens quality.
SuperCode	S	X	O				O			U	
Ultracode	M.	O	O				X		O	U	
VeriCode®	M	O	O			O	O	O	O	R	
VSCode®	M	O	O			O	O	O	O	R	Greatest in density.
VisualCode	M	O				O	O				

* △: Partially Omni-directional

Each row is coloured according to the criteria in the table below.

2D-barcodes that satisfy all requirements
2D-barcodes that satisfy 7 requirements
2D-barcodes that satisfy 6 requirements
2D-barcodes that satisfy 5 requirements
2D-barcodes that satisfy 4 requirements
2D-barcodes that satisfy less than 4 requirements

Appendix 6: Sample 2D-barcodes for the 2nd Assessment

Small sized 2D-symbols (S-symbols)

1. Secure 2D Code	2. Data Matrix	3. QR code	4. DataGlyphs	5. VSCode®	6. CP Code
7. INTACTA.CODE	8. Datastrip Code	9. MiniCode	10. Snowflake Code	11. ShotCode	12. Visual Code

Large sized 2D-symbols (L-symbols)

13. Secure 2D Code	14. Data Matrix	15. QR code	16. DataGlyphs
17. VSCode®	18. CP Code	19. INTACTA.CODE	20. Datastrip Code
21. MiniCode	22. Snowflake Code	23. ShotCode	24. Visual Code

Cell-Resized 2D-symbols (CR-symbols)

25. Data Matrix	26. QR code	27. DataGlyphs	28. VSCode®	29. CP Code

※ Each Number placed in front of each symbol name indicates Sample-ID.

Figure 62: Sample 2D-barcodes for the 2nd Assessment

Appendix 7: The Specification of the Mobile Phone used for the 2nd Experiments

Table 31: Sagem myC5-2 Specification

Figure 63: Image of Sagem MyC5-2

Sagem myC5-2 Provisional Specifications	
Available:	Q4 2004
Network:	Tri-band GSM (tbc)
Data:	GPRS
Screen:	128x160 pixels, 65,000 colours
Camera:	640x480 pixels
Size:	Compact clamshell 82x43x23mm / 80 grams approx
Bluetooth:	No
Infra-red:	Not specified
Polyphonic:	Yes
Java:	Yes
Battery life:	Not specified

Source: Sagem myC5-2. (Mobile Gazette and Representatives, 2005). Retrieved, August 05, 2005, from http://www.mobilegazette.com/sagem-myc5-2.htm

Appendix 8: The result of the 2nd Assessment – PSNR Value for each symbol

Table 32: PSNR Values for S-symbols (approximately 2.5 cm²)

S ID	Symbology Name	PSNR						
			Full Light	Half Light (V)	Half Light (H)	Half Light (M)	No Light	Mean
1	Secure 2D	PSNR	26.6015	26.6005	26.6022	26.6014	26.5946	26.5997
		mse	142.2109	142.2439	142.1858	142.2149	142.4351	142.2581
2	Data Matrix	PSNR	27.2658	27.2614	27.2639	27.2627	27.2523	27.2612
		mse	122.0399	122.1643	122.0919	122.1281	122.4203	122.1689
3	QR Code	PSNR	26.8681	26.8725	26.8663	26.8694	26.8621	26.8677
		mse	133.7435	133.6070	133.7978	133.7024	133.9274	133.7556
4	DataGlyphs	PSNR	25.4447	25.4446	25.4447	25.4447	25.4433	25.4444
		mse	185.6155	185.6169	185.6154	185.6162	185.6717	185.6271
5	VSCode®	PSNR	27.2706	27.2740	27.2709	27.2725	27.2518	27.2680
		mse	121.9038	121.8102	121.8959	121.8531	122.4344	121.9795
6	CPCode	PSNR	26.7822	26.7900	26.7801	26.78505	26.767	26.7809
		mse	136.4151	136.1692	136.4815	136.3254	136.8936	136.4570
7	INTACTA code	PSNR	27.4242	27.4312	27.4296	27.4304	27.3951	27.4221
		mse	117.6672	117.4778	117.5213	117.4996	118.4587	117.7249
8	Datastrip Code	PSNR	27.6664	27.6659	27.6654	27.6657	27.6572	27.6641
		mse	111.2865	111.2995	111.3120	111.3058	111.5228	111.3453
9	MiniCode	PSNR	26.4273	26.4274	26.4274	26.4274	26.401	26.4221
		mse	148.031	148.0264	148.0278	148.0271	148.9297	148.2084
10	Snowflake	PSNR	24.6703	24.6602	24.6938	24.6770	24.5281	24.6459
		mse	221.8462	222.3611	220.6493	221.5052	229.2294	223.1182
11	ShotCode	PSNR	26.4197	26.4245	26.4266	26.4256	26.4132	26.4219
		mse	148.2884	148.1265	148.0555	148.0910	148.511	148.2145
12	VisualCode	PSNR	27.7457	27.7407	27.7419	27.7413	27.7322	27.7404
		mse	109.2712	109.3976	109.3678	109.3827	109.6133	109.4065
PSNR (M)			26.7155	26.7161	26.7177	26.7169	26.6915	26.7115
MSE (M)			141.5266	141.5250	141.4168	141.4709	142.5040	141.6887

※ Both PSNR values and mse are rounded off to four decimal places and presented in the table.

Table 33: PSNR Values for L-symbols (approximately 5.0 cm²)

S ID	Symbology Name	PSNR						
			Full Light	Half Light (V)	Half Light (H)	Half Light (M)	No Light	Mean
13	Secure 2D	PSNR	26.7084	26.7072	26.7086	26.7079	26.7055	26.7075
		mse	138.7518	138.7893	138.7465	138.7679	138.8458	138.7834
14	Data Matrix	PSNR	27.2433	27.2457	27.2412	27.2435	27.2371	27.2418
		mse	122.6729	122.6059	122.7313	122.6686	122.8473	122.7144
15	QR Code	PSNR	26.2829	26.2819	26.2818	26.2819	26.2772	26.2810
		mse	153.0333	153.069	153.0748	153.0719	153.2347	153.1030
16	DataGlyphs	PSNR	25.4284	25.4282	25.4284	25.4283	25.4283	25.4283
		mse	186.3114	186.3196	186.3121	186.3159	186.3182	186.3153
17	VSCode®	PSNR	26.9362	26.9295	26.9422	26.9359	26.9132	26.9303
		mse	131.6623	131.8647	131.4805	131.6726	132.3613	131.8422
18	CPCode	PSNR	26.6649	26.6649	26.7111	26.6880	26.6517	26.6732
		mse	140.1495	140.1495	138.6657	139.4076	140.5769	139.8854
19	INTACTA code	PSNR	27.7403	27.7358	27.7364	27.7361	27.7141	27.7317
		mse	109.4092	109.5208	109.5055	109.5132	110.0703	109.6265
20	Datastrip Code	PSNR	27.7540	27.7535	27.7532	27.75335	27.7445	27.7513
		mse	109.0634	109.0757	109.0835	109.0796	109.3033	109.1315
21	MiniCode	PSNR	26.5042	26.5005	26.5028	26.5017	26.4882	26.4989
		mse	145.4324	145.5567	145.4780	145.5174	145.9704	145.6094
22	Snowflake	PSNR	24.6368	24.6534	24.6703	24.6619	24.5308	24.6228
		mse	223.5628	222.7087	221.8447	222.2767	229.0848	224.3003
23	ShotCode	PSNR	26.1553	26.1533	26.1716	26.1625	26.1487	26.1572
		mse	157.5971	157.6712	157.0085	157.3399	157.8358	157.5282
24	VisualCode	PSNR	28.5158	27.9133	28.1946	28.0540	27.5892	28.0532
		mse	91.5161	105.1356	98.5408	101.8382	113.2815	102.1185
PSNR (M)			26.7142	26.6639	26.6952	26.6796	26.6190	26.6731
MSE (M)			142.4302	143.5389	142.7060	143.122442	144.9775	143.4131

※ Both PSNR values and mse are rounded off to four decimal places and presented in the table.

Table 34: PSNR Values for CR-symbols (approximately 5.0 cm²)

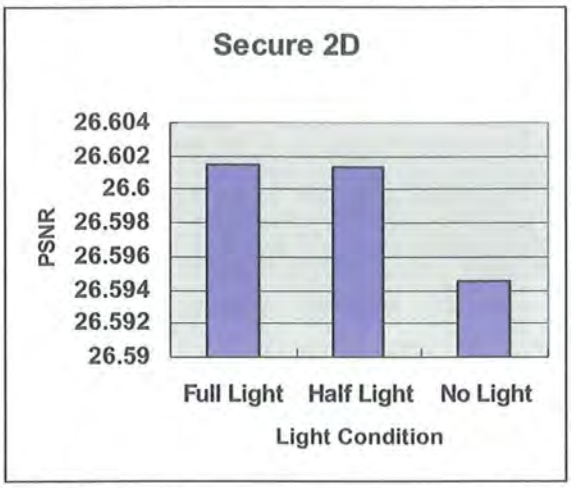
S ID	Symbology Name	PSNR						
			Full Light	Half Light (V)	Half Light (H)	Half Light (M)	No Light	Mean
25	Data Matrix	PSNR	27.3689	27.3662	27.3749	27.37055	27.3612	27.3678
		mse	119.1766	119.2492	119.0113	119.13025	119.3873	119.2061
26	QR code	PSNR	27.0646	27.0643	27.0693	27.0668	27.0568	27.0638
		mse	127.8255	127.8355	127.6876	127.76155	128.0557	127.8511
27	DataGlyphs	PSNR	25.5556	25.5556	25.5556	25.5556	25.5543	25.5553
		mse	180.9348	180.9324	180.9322	180.9323	180.9890	180.9471
28	VS Code	PSNR	27.5954	27.5909	27.5869	27.5889	27.5722	27.5864
		mse	113.1213	113.2375	113.3426	113.29005	113.7269	113.3571
29	CP Code	PSNR	27.2628	27.2640	27.2599	27.26195	27.2529	27.2599
		mse	122.1244	122.0900	122.2048	122.1474	122.4029	122.2055
PSNR (M)			26.9695	26.9682	26.9693	26.9688	26.9595	26.9666
MSE (M)			132.6365	132.6689	132.6357	132.6523	132.9124	132.7134

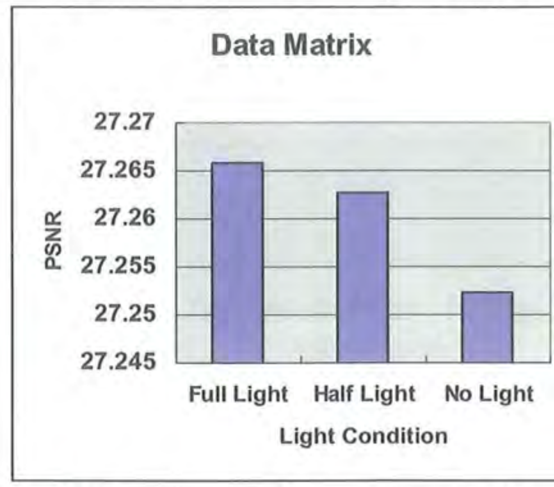
※ Both PSNR values and mse are rounded off to four decimal places and presented in the table.

Appendix 9: Difference in PSNR Value of each 2D symbol under varying light conditions

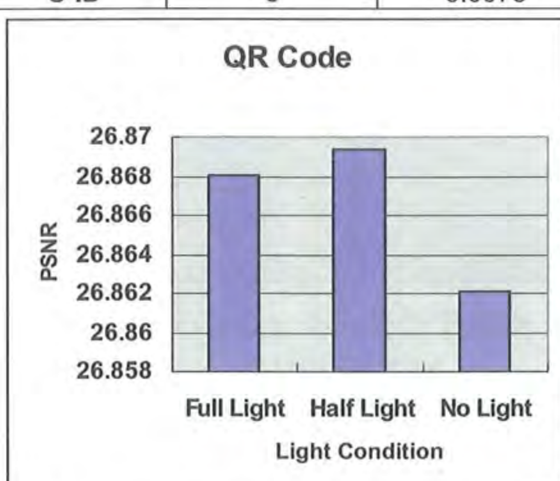
1. S-symbols

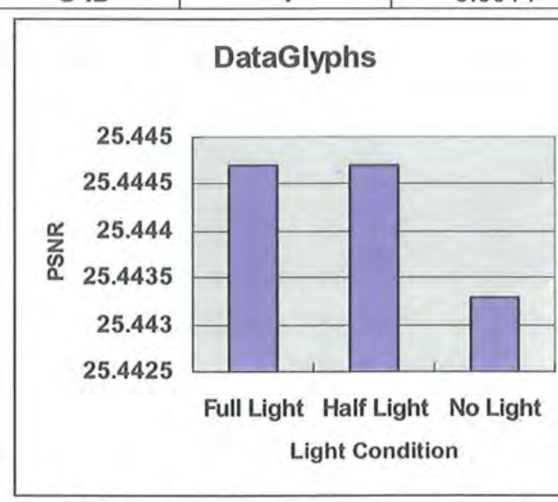
S-ID	1	0.0069	S-ID	2	0.0135



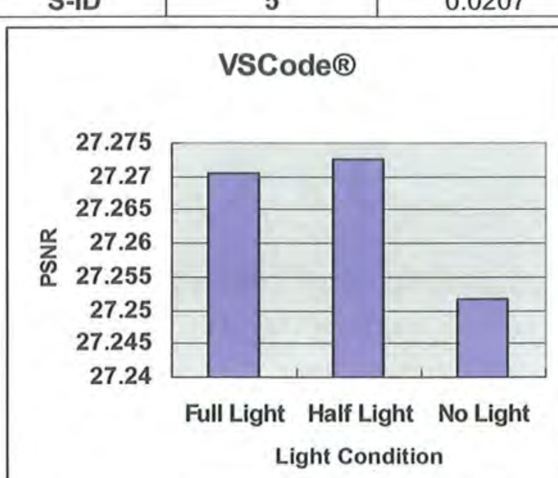


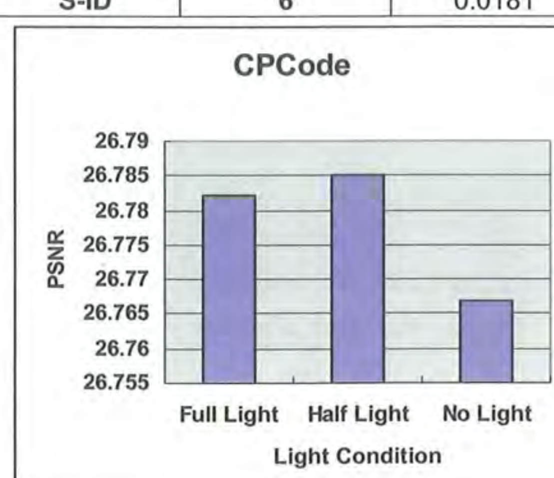
S-ID	3	0.0073	S-ID	4	0.0014



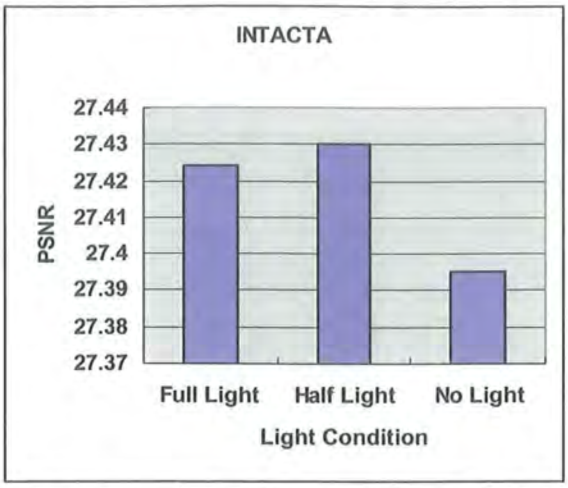


S-ID	5	0.0207	S-ID	6	0.0181

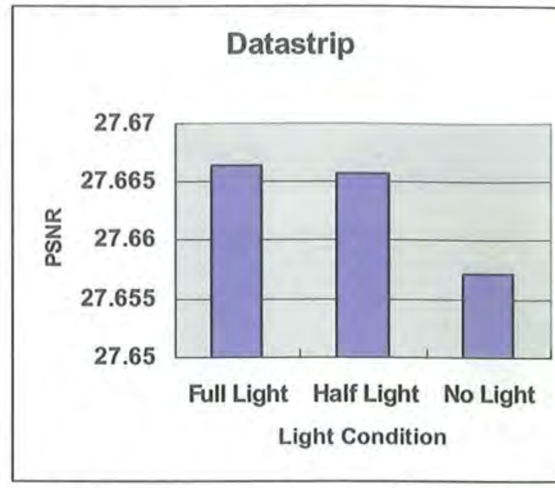




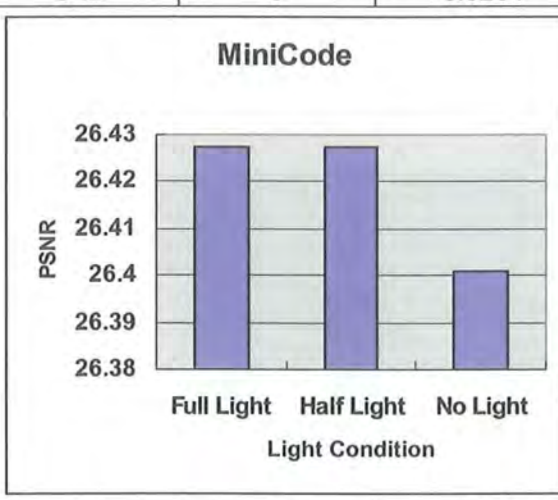
S-ID	7	0.0353



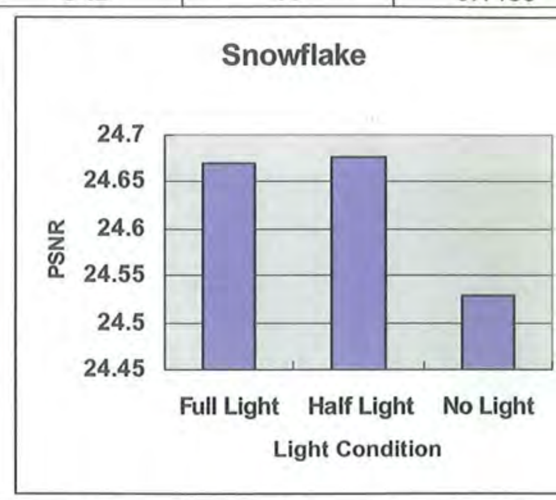
S-ID	8	0.0092



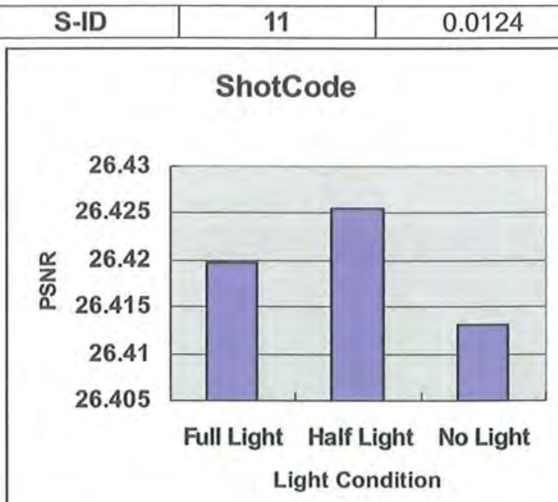
S-ID	9	0.0264



S-ID	10	0.1489



S-ID	11	0.0124



S-ID	12	0.0135

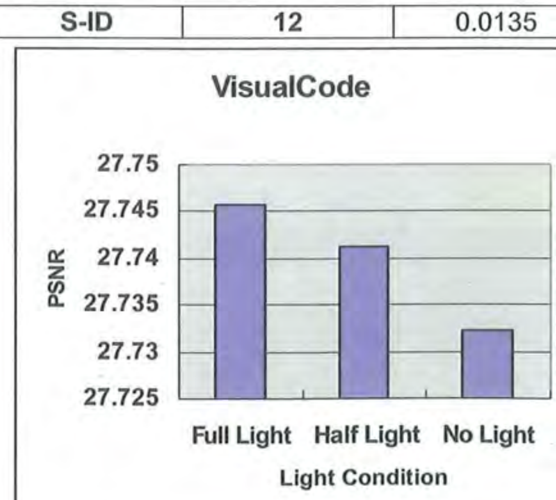
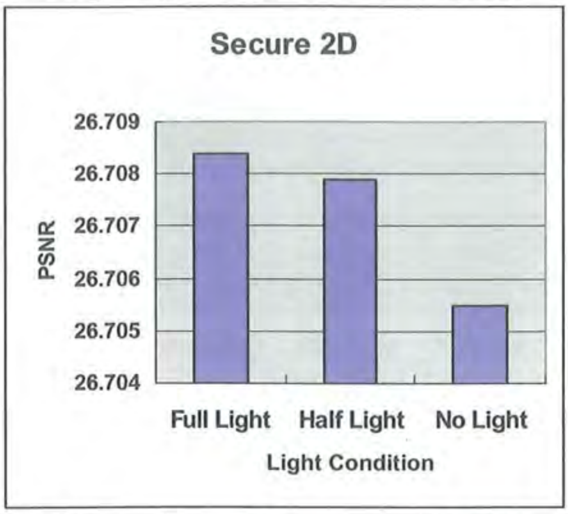
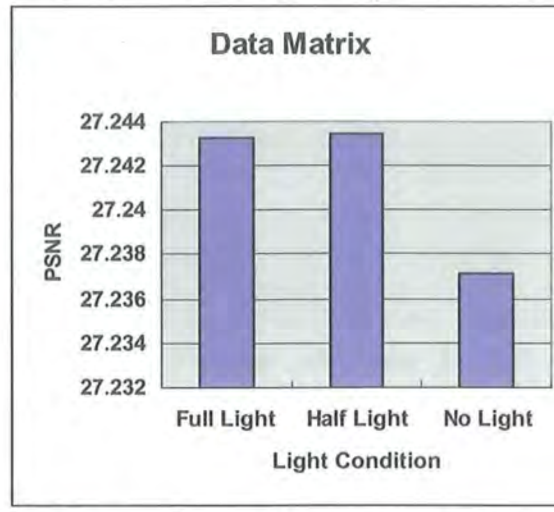


Figure 64: Difference in PSNR Value of Each 2D Code under varying light Condition (S-symbols)

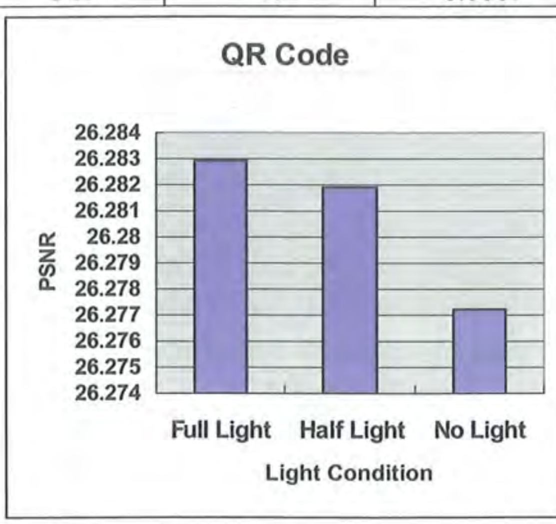
2. L-symbols

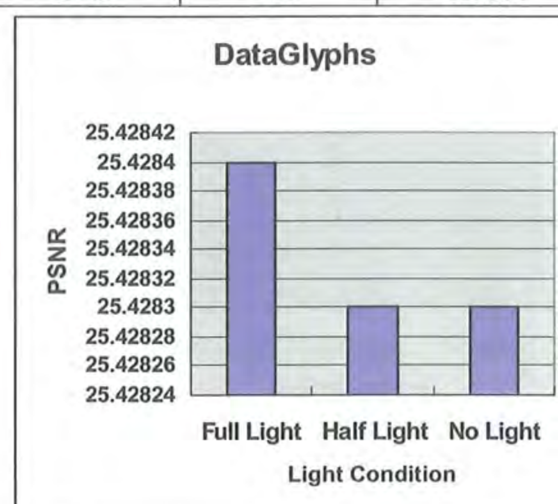
S-ID	13	0.0029	S-ID	14	0.0064



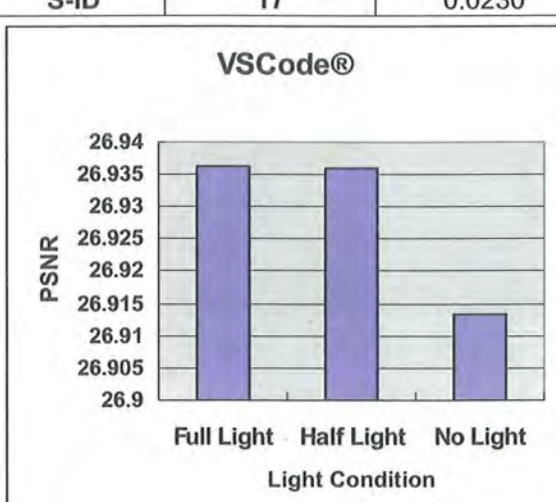


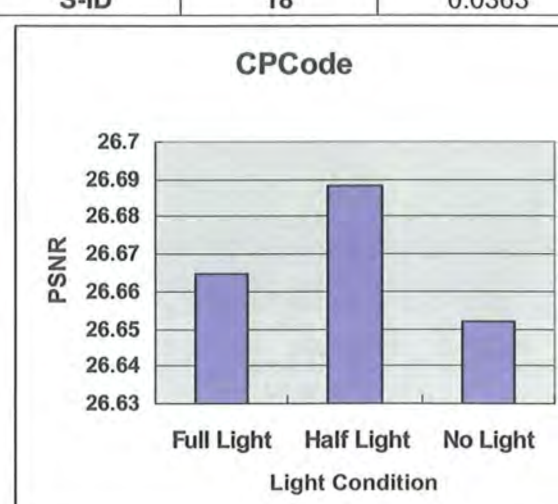
S-ID	15	0.0057	S-ID	16	0.0001



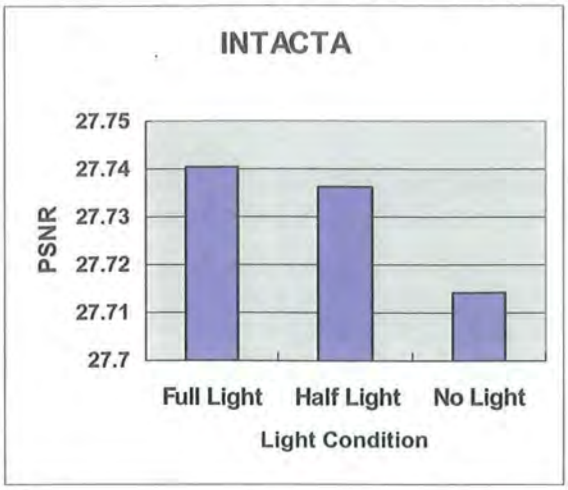


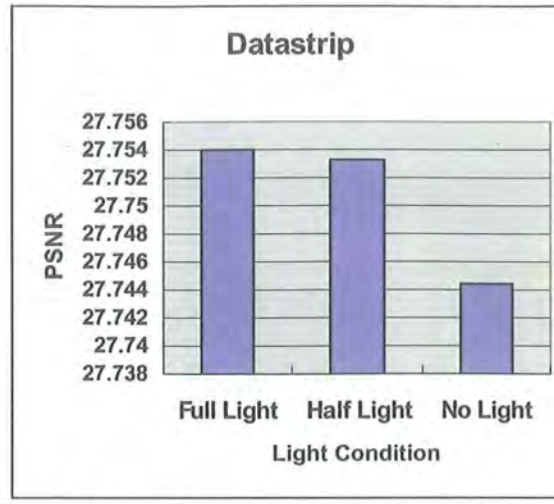
S-ID	17	0.0230	S-ID	18	0.0363



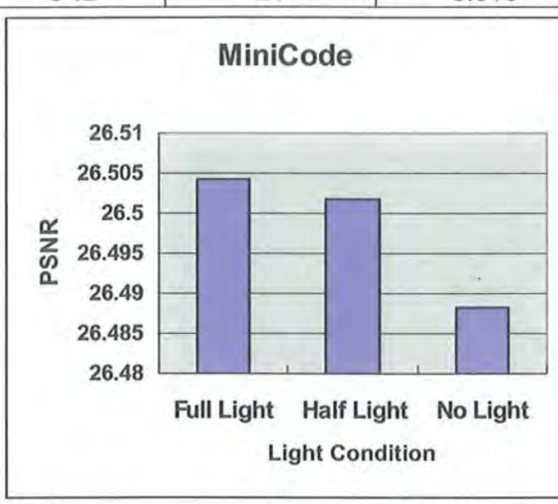


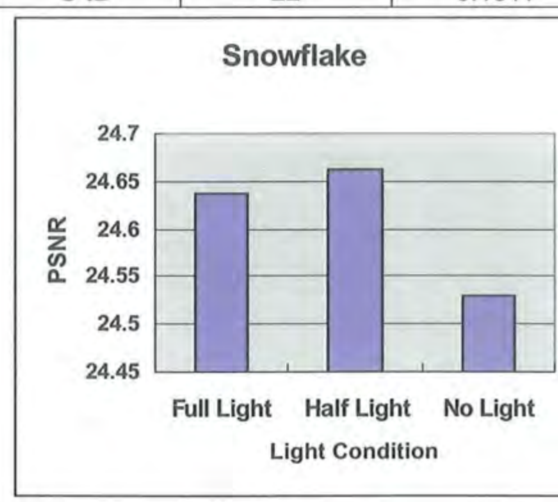
S-ID	19	0.0262	S-ID	20	0.0095



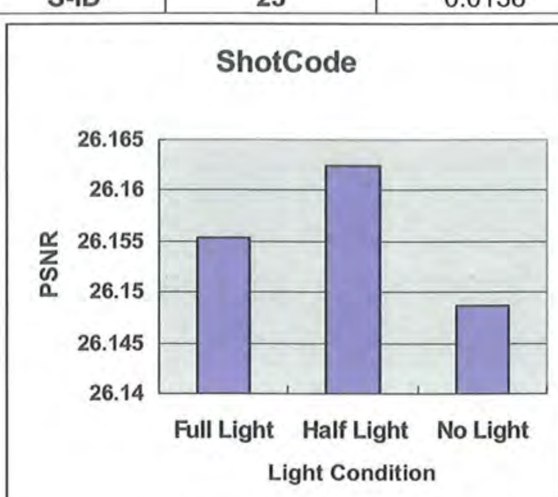


S-ID	21	0.016	S-ID	22	0.1311





S-ID	23	0.0138	S-ID	24	0.9266



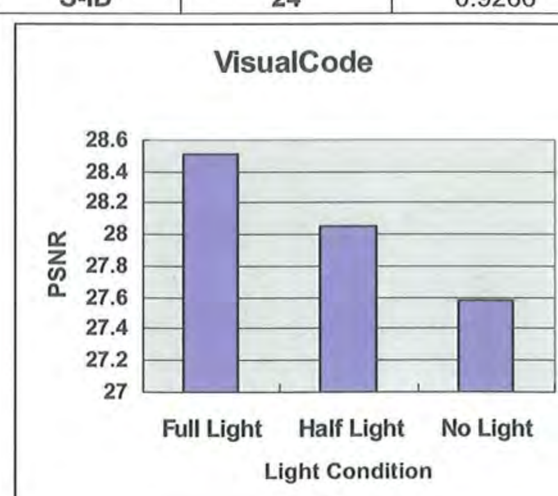
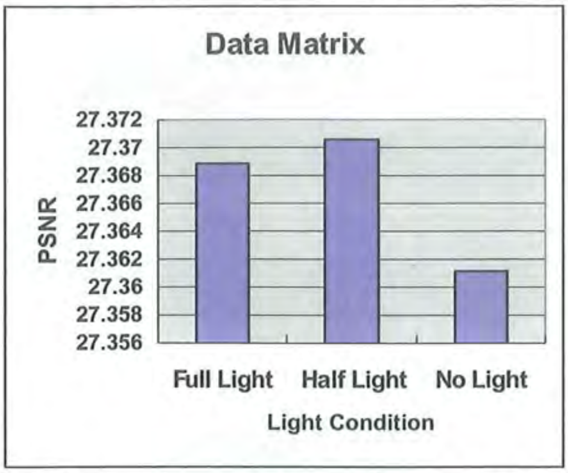


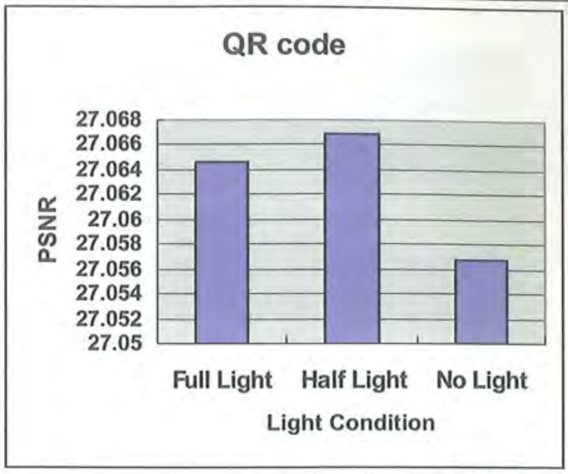
Figure 65: Difference in PSNR Value of Each 2D Code under Varying Light Conditions (L-symbols)

3. CR-symbols

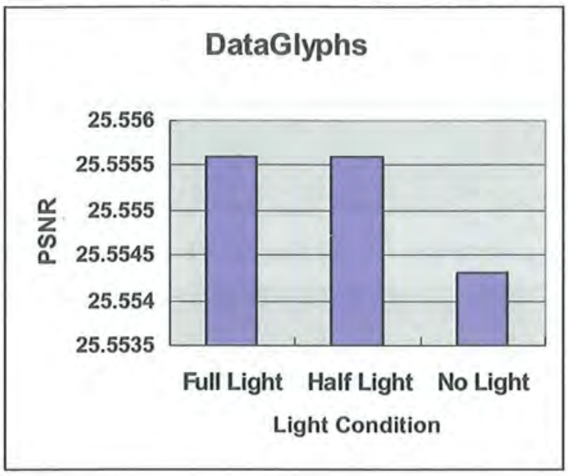
S-ID	25	0.00935



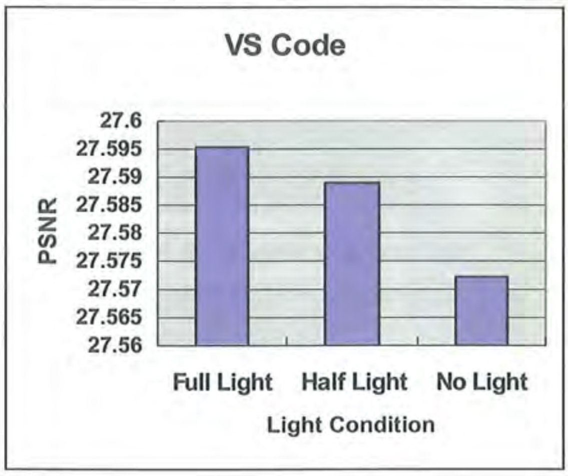
S-ID	26	0.0100



S-ID	27	0.0013



S-ID	28	0.0232



S-ID	29	0.0099

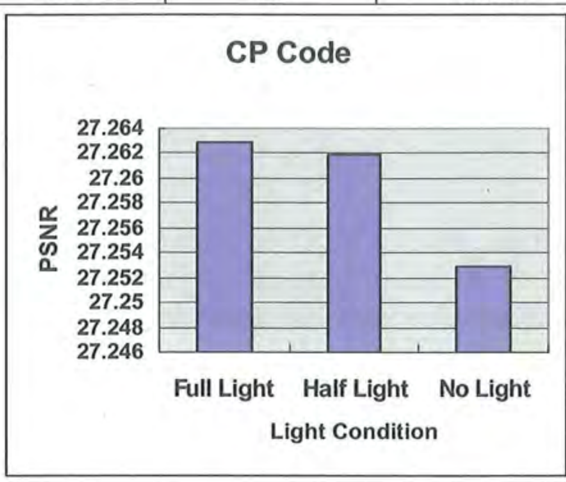


Figure 66: Difference in PSNR Value of Each 2D Code under Varying Light Conditions (CR-symbols)

Appendix 10: The 2nd Assessment Final Result for all the sample 2D-barcodes

Table 35: The result for 2D-barcode in Public domain

2D- Symbology	No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
Secure 2D code	8	M	O	O	O	O	O	O	O	O	N/A	2 security layers, Data hiding
Data Matrix	7	M	O	O	O	O	O	O	/	O	U	Scalable in size.
Semacode	6	M	O	O	O	O	O	O	/	/	U	
Mobile code	8	M	O	O	O	O	O	O	O	O	U	Scalable in size.
MS-CODE	8	M	O	O	O	O	O	O	O	O	U	Scalable in size.
QR Code	7	M	O	O	O	O	O	O	/	O	U	Scalable in size. Can be divided.
Micro QR Code	6	M	O	O	O	O	O	×	/	O	U	Scalable in size.

Table 36: The result for 2D-barcode in Proprietary domain

2D- Symbology	No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
DataGlyphs	6	M	O	O	O	×	×	O	O	O	R	Adjustable size, shape and color
VeriCode®	8	M	O	O	O	O	O	O	O	O	R	Scalable in size.
VSCode®	8	M	O	O	O	O	O	O	O	O	R	Scalable in size. Greatest in density.
CP Code	8	M	O	O	O	O	O	O	O	O	R	
INTACTA.CODE	7	M	/	O	O	O	O	O	O	O	R	Scalable in size. Data compression.
Datastrip Code	7	S	×	O	O	O	O	O	O	O	R	Resistant to alteration.
MiniCode	6	M	O	O	O	O	O	O	/	/	R	Scalable in resolution.
Snowflake Code	3	M	O	O	×	×	×	O	/	/	R	

Table 37: The result for 2D-barcodes specifically designed for mobile applications

2D- Symbology	No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11. Additional Feature(s)
ShotCode (SpotCode)	4	M	O	/	O	O	O	/	/	/	/	Works irrespective of lens quality.
VisualCode	5	M	O	/	O	O	O	O	/	/	/	Code coordinate system.

Legend: refer to the legend provided in p.151.

Note: When no information is provided, an oblique line is placed in the box (i.e. /)

Note 1: The results include the result of derivative 2D-barcodes whose original symbols were examined.

Note 2:
It is presumed that INTACTA Code satisfies the 2nd criterion, namely, Omni-directional reading. However, no information about the angle-free reading capability of INTACTA Code has been found yet. Hence, the result remains as shown in the table.

Note 3:
From the literature and/or specification, it is believed that Snowflake code can satisfy the light criterion. However, it appears that Snowflake code is not satisfactory against the light criteria in the experiment. Accordingly, the number of criteria that Snowflake code can satisfy has been reduced from 4 to 3.