General Description of QR Code

1. The Background of its Development

Described below is the background of the development of QR code starting from the history of linear bar code symbols. In 1970, IBM developed UPC symbols consisted of 13 digits of numbers to enable automatic input into computers.These UPC symbols are still widely used for POS system. In 1974, Code 39 which can encode (symbolize) approx. 30 digits of alphanumeric characters was developed. Then in the early 1980s, multistaged symbol codes where approx. 100 digits of characters can be stored such as Code 16K and Code 49 were developed. As informatization had rapidly developed in the recent years, requests had mounted for symbols where more information amount can be stored and where languages other than English can be represented. To enable this, a symbol with even higher density than multistaged symbols was required. As a result, QR Code, which can contain 7,000 digits of characters at maximum including Kanji characters (Chinese characters used in Japan) had been developed in 1994.

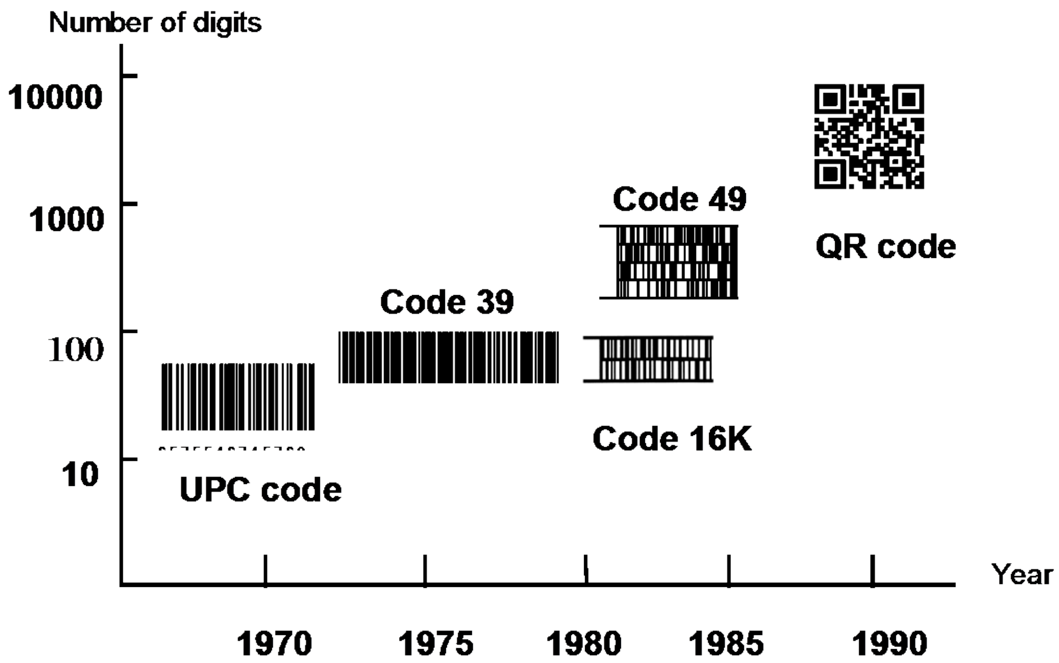

Fig. 1 History of Symbols

The history until realizing high-capacity and high-density symbols can be described as illustrated in Fig. 2 when seeing them from the technology's aspect. Firstly, Interleaved 2 of 5 and Codabar which can encode (symbolize) numbers had been developed, and then Code 39 which can encode alphanumerical characters had been developed. Along with the development of informatization, it had become required to have full ASCII enocded, and this resulted in the development of Code 128. Then, multistaged symbols were developed where these linear symbols were arranged in several stages. Toyota Motor's Kanban Code is the world's first multistaged symbol. As computers became popular, these codes developed into multi-row symbols where multistaged codes were extended and into matrix symbols where data were arranged in matrix. The printing area for matrix symbols are the smallest among all, and is seen as highly prospective as the main symbol for the future. QR Code is a matrix symbol which has been developed as the one enabling all of high capacity PDF417, high density printing of data matrix, and high speed reading of maxi code based on the research made on their characteristics. Two-dimensional symbols generally contain much more data amount when compared with linear symbols (approx. 100 times more), and therefore require much longer data processing time and more complex process. Therefore, QR Code has had much consideration for its finder pattern to enable high-speed reading.

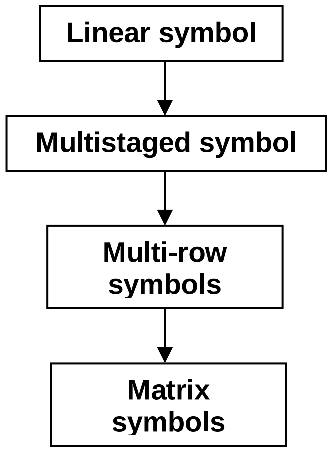

Fig. 2 Development of Symbols

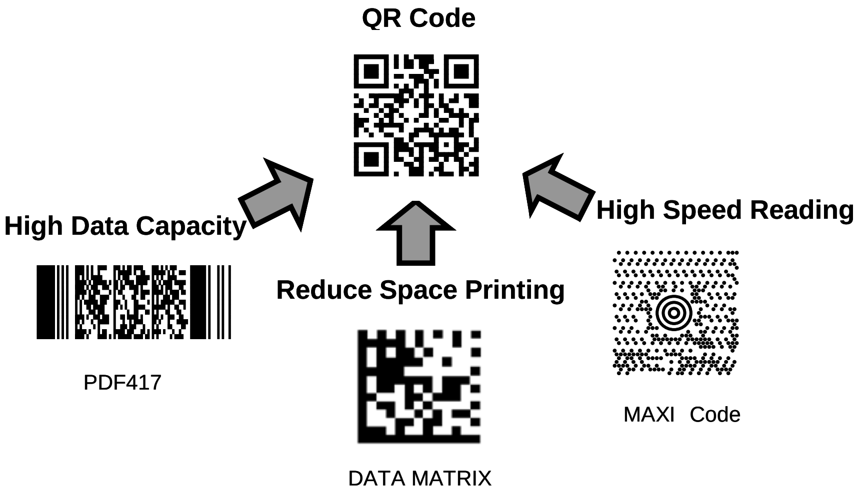

Fig. 3 Development of QR Code

2. Characteristics of the QR Code

Additionally to the characteristics for two-dimensional symbols such as large volume data (7089 numerical characters at maximum), high-density recording (approx. 100 times higher in density than linear symbols), and high-speed reading, QR Code has other superiority in both performance and functionalities aspects.

2-1. All-direction (360°) high-speed reading

Reading matrix symbols will be implemented by using a CCD sensor (area sensor). The data of the scan line captured by the sensor will be stored into the memory. Then, by using the software, the details will be analyzed , finder patterns identified, and the posotion / size / angle of the symbol

detected, and then the decoding process will be implemented. Traditional two-dimensional symbols used to take much time for detecting the position / angle / size of the symbol, and had a problem that their reading feelings were less accurate when compared with those for linear symbols. QR Code has finder patterns for notifying the position of the symbol arranged in 3 of its corners to enable high-speed reading in all directions (360°). The ratio between black and white among the scan line that runs through the finder patterns is always 1:1:3:1:1 when seen from any direction among the 360° surrounding it. By detecting this specific ratio, the finder pattern can be detected from among the image captured by the CCD sensor in a short period of time to identify the position of the QR Code in a short period of time. Additionally, by identifying the positional relationships of the 3 finder patterns listed in Fig. 5 from among the image field of the CCD sensor, the size (L), the angle (θ), and the outer shape of the symbol can be simultaneously detected.
By arranging the finder patterns into the 3 corners of the symbol, the decoding speed of the QR Code can be made 20 times faster than that of other matrix symbols. Additionally, detecting finder patterns can be easily implemetned by the hardware, and can also be accelerated.

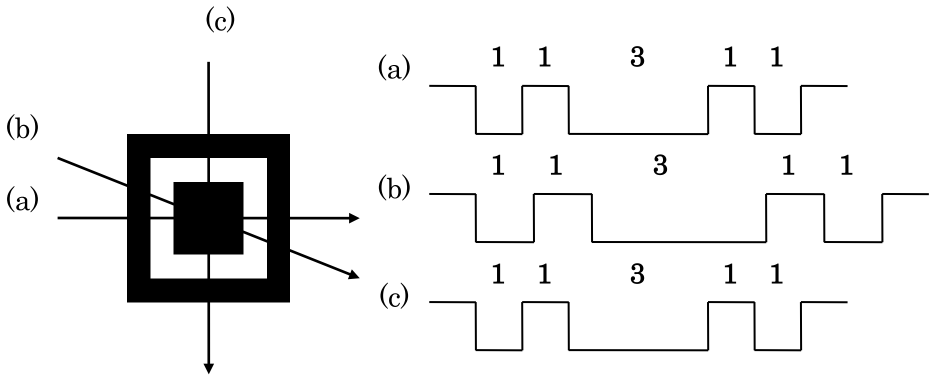

Fig. 4 Finder Patterns

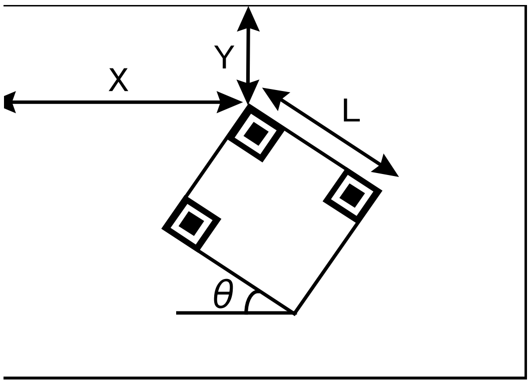

Fig. 5 Identifying a QR Code

2-2. Resistant to Distorted Symbols

Symbols often get distorted by being attached onto a curved surface or by the reader being tilted (angled between the CCD sensor face and the symbol face). To correct this distortion, QR Code has alignment patterns arranged with a regular interval within the range of the symbol. The variance between the center position of the alignment pattern estimated from the outer shape of the symbol and the acutal center position of the alignment pattern will be calculated to have the mappings (for identifying the center position of each cell) corrected. This will enable to make the distorted linear/non-linear symbols readable.

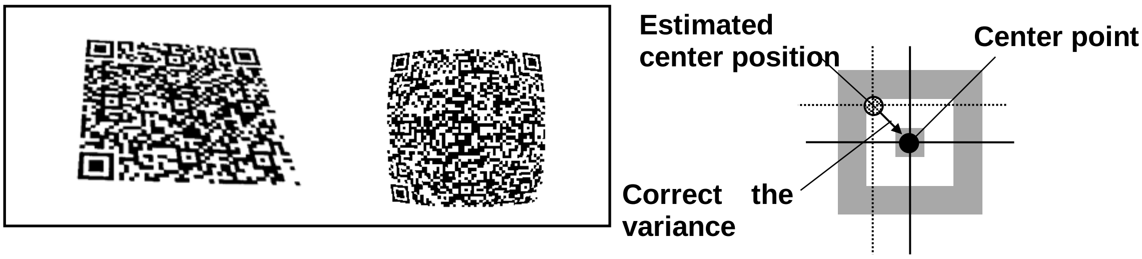

Fig. 6 Correcting Distorted Symbols

2-3. Data Restoration Functionality (Resistant to Smudged or Damaged Symbols)

QR Code has 4 different error correction levels (7%, 15%, 25%, and 30% per symbol area). The error correction functionality is implemented according to each of the smudge / damage, and is utilizing Reed-Solomon code which is highly resistant to burst errors. Reed-Solomon codes are arranged in the QR Code data area. By this error correction functionality, the codes can be read correctly even when they are smudged of damaged up until the error correction level. The error correction level can be configured by the user when he/she creates the symbol, so if the code is highly possible to get smudged in the users' usage environment, it is recommended to have 30% set for this correction level.

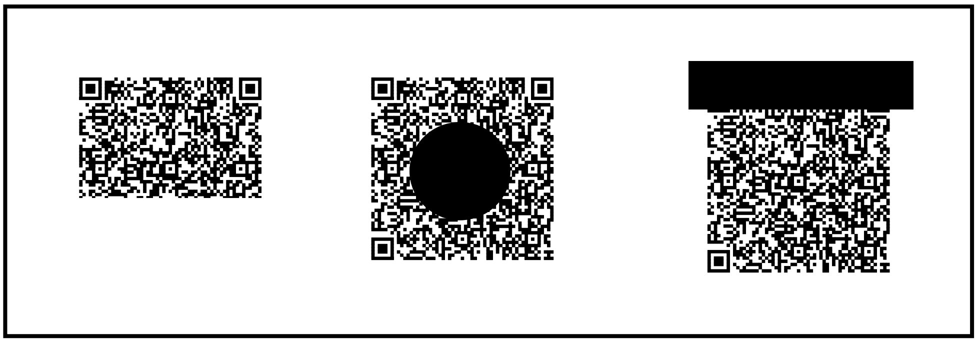

Fig. 7 Smudged / Damaged Symbols

2-4. Efficiently Encoding Kanji Characters and Kana Characters

QR Code has been developed based on the premise that it will be used in Japan. The specifications for the symbol has efficiently encoded JIS level-1 & 2 Kanji and Kana characters. When making Japanese expressions using other two-dimensional symbols, the expression would have to be made in binaries and would therefore require 16 bits (2 bytes) for a single character, whereas QR Code has each Japanese character encoded in 13 bits. This means that QR Code can have Japanese letters encoded 20% more efficiently than other two-dimensional symbols. In other words, if the data volume is the same, the symbol can be generated in a smaller area. Codes in each country will be using the language in that specific country, and this functionality will enable encoding of the specific language in an efficient manner, such as having Chinese characters for China and Vietnamese for Vietnam efficiently encoded.

2-5. Linking Functionality of the Symbols

QR Code has a linking functionality. Linking functionality will enable a single symbol to be represented in several symbols by dividing it . A single symbol can be divided into 16 symbols at maximum. The example shown in Fig. 8 is one where a single QR Code is divided into 4 symbols, and each symbol has an indicator showing how many symbols the original symbol had been divided into and in which order that specific symbol would be among all divided ones. This will enable the entire data to be edited and submitted to the computer regardless of what order the symbols had been read by the reader. By this linking functionality, the QR Code will be able to be printed even if the printing space is not wide enough to have a single QR Code printed.

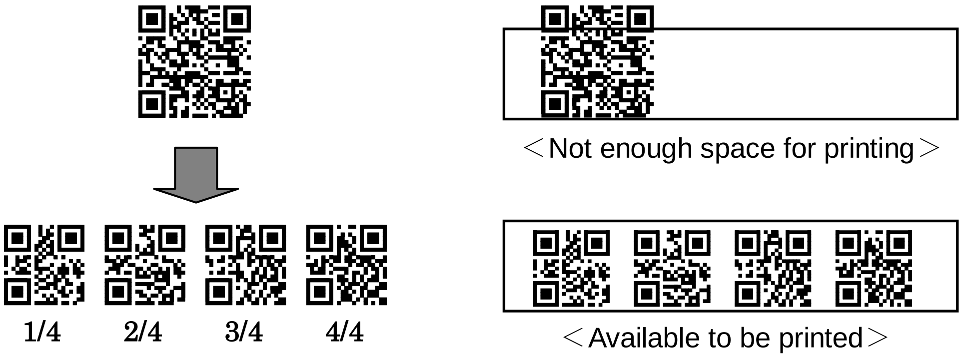

Fig. 8 Linking the Symbols

2-6. Masking Process

By having special patterns to process masking, QR Code is enabled to have black and white cells well arranged in a balanced order. To accurately binalize the data that had been read, it is necessary to arrange the white cells and the black cells in a well-balanced manner. To enable this, EX-OR calculation will be implemented between the data area cell and the mask pattern (template) cell when encoding the stored data and arranging it into the data area. Then, the number of unique patterns exisiting and the balance between the white cells and the black cells will be assessed against the data area where the calculation had been implemented. There are 8 mask patterns. Assessment will be made for each mask pattern, and the mask pattern with the highest assessment result together with the EX-OR calculation result will be stored into the data area.

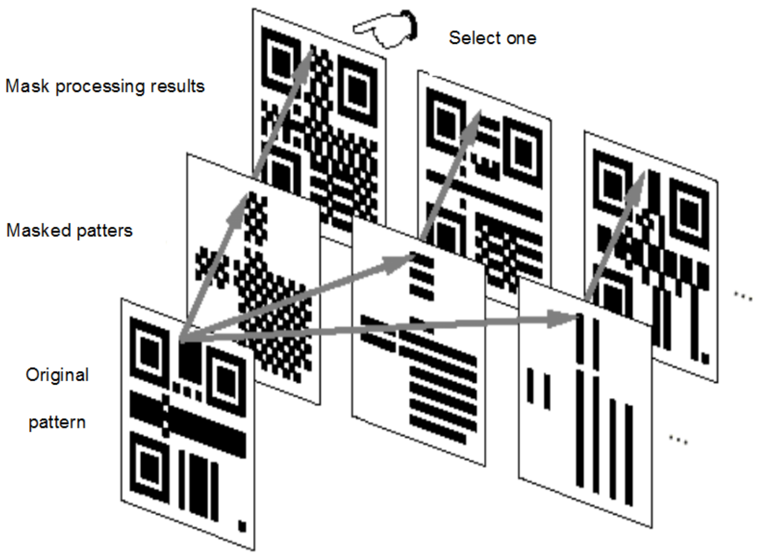

Fig. 9 Masking Process

2-7. The Confidentiality of the Code

By making the relationship between the character type and the stored data unique for a special usage, QR Code can be easily encrypted. Unless the conversion table between the character type and the stored data is deciphered, no one will be able to read the QR Code.

2-8. Direct Marking

QR Code exerts superior readability even for symbols where they are directly marked using laser or dot pin markers. For directly marked symbols, the cell shape does not necessarily have to be square as shown in Fig. 10. It can also be circular shape. Even if the white part (with high reflectance) and the black part (with low reflectance) are inverted due to the angle of the illuminating ray, the code is highly assured to be read in an accurate manner. It is also possible to read from the back side of the symbol when it is marked upon a transparant material such as glass, etc.

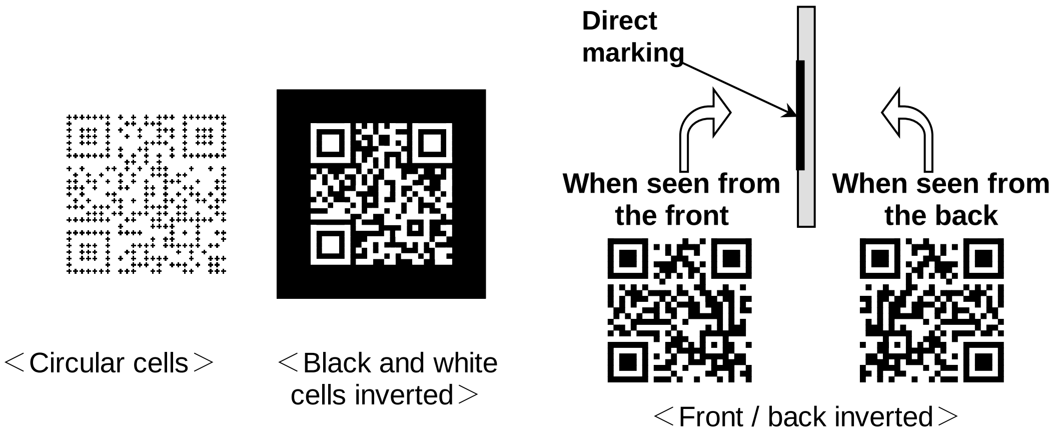

Fig. 10 Direct Marking

3. QR Code Structure

QR Code is a matrix type symbol with a cell structure arranged in a square. It is consisted of the functionality patterns for making the reading easier and the data area where the data is stored. QR Code has finder patterns, alignment patterns, timing patterns, and a quiet zone.

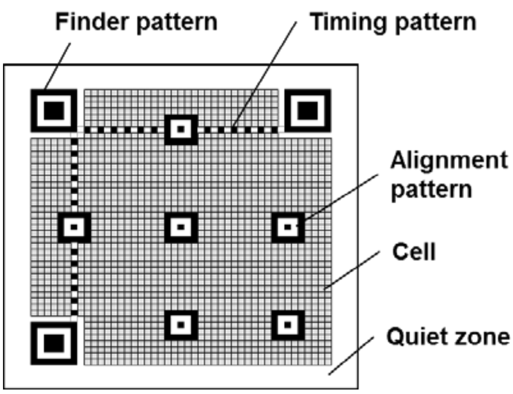

Fig. 11 QR Code Structure

3-1. Finder Pattern

A pattern for detecting the position of the QR Code. By arranging this pattern at the 3 corners of a symbol, the position, the size, and the angle of the symbol can be detected. This finder pattern is consisted of a structure which can be detected in all directions (360°). (Please refer to 2-1)

3-2. Alignment Pattern

A pattern for correcting the distortion of the QR Code. It is highly effective for correcting nonlinear distortions. The central coordinate of the alignment pattern will be identified to correct the distortion of the symbol. For this purpose, a black isolated cell is placed in the alignment pattern to make it easier to detect the central coordinate of the alignment pattern. (Please refer to 2-2)

3-3. Timing Pattern

A pattern for identifying the central coordinate of each cell in the QR Code with black and white patterns arranged alternately. It is used for correcting the central coordinate of the data cell when the symbol is distorted or when there is an error for the cell pitch. It is arranged in both vertical and horizontal directions. (Please refer to 2-2)

3-4. Quiet Zone

A margin space necessary for reading the QR Code. This quiet zone makes it easier to have the symbol detected from among the image read by the CCD sensor. 4 or more cells are necessary for the quiet zone.

3-5. Data Area

The QR Code data will be stored (encoded) into the data area. The grey part in Fig. 11 represents the data area. The data will be encoded into the binary numbers of '0' and '1' based on the encoding rule. The binary numbers of '0' and '1' will be converted into black and white cells and then will be arranged. The data area will have Reed-Solomon codes incorporated for the stored data and the error correction functionality.

4. The Specifications of the QR Code

The specifications of the QR Code are as described in Table 1.

4-1. Symbol Size

QR Code can have its size freely selected according to the data volume to be stored and the reading method. The symbol size is incremented by 4 cells in both vertical and horizontal direction – 21x21 cells, 25x25 cells, 29x29 cells…, and there are 40 size types with the maximum size set to 177x177 cells.

For example, in the case for 45x45 cells, if a single square cell is sized 0.25mm, one side of the symbol will be 45x0.25mm = 11.25mm. The quiet zone will be needed to be added on both sides of the symbol whose minimum size is 4 cells, and therefore, the space required for having this symbol printed will be a square of; (4+45+4)×0.25mm＝13.25mm.

4-2. Information type and volume

QR Code can handle various types of data such as numerical characters, alphabets, signs, Kanji characters, Hiragana, Katakana, control signs, and images. It basically can have character sets supported by ISO/IEC 646 and ISO/IEC 10646 used. These data can also coexist. The maximum available volume of the information is listed in Table 1.

4-3. Data Conversion Efficiency

QR Code has 4 types of conversion mode – numerical characters, alphanumerical / signs, binary, and Kanji characters – for encoding the data. Each mode has had considerations to improve its conversion efficiency. The number of cells required for each character in each mode is listed in Table 1.

4-4. Error Correction Functionality

QR Code has an error correction functionality for restoring the data. There are 4 different restoration levels so that you can select the level that matches with each usage environment. Each restoration capability is as listed in Table 1.

Table1. Specifications of the QR Code

Symbol size	Min. 21x21 cell – Max. 177x177 cell (with 4-cells interval)	
Information type and volume	Numerical characters	7089 characters at maximum
	Alphabets, signs	4296 characters at maximum
	Binary (8 bit)	2953 characters at maximum
	Kanji characters	1817 characters at maximum
Conversion efficiency	Numerical characters mode	3.3 cells / character
	Alphanumerical / signs mode	5.5 cells / character
	Binary (8 bit) mode	8 cells / character
	Kanji character mode (13 bit)	13 cells / character
Error correction functionality	Level L	Approx. 7% of the symbol area restored at maximum
	Level M	Approx. 15% of the symbol area restored at maximum
	Level Q	Approx. 25% of the symbol area restored at maximum
	Level H	Approx. 30% of the symbol area restored at maximum
Linking functionality	Possible to be divided into 16 symbols at maximum	

5. Standardizing the QR Code

5-1. QR Code Standards

To make QR Code widely spread, the infrastructure needs to be maintained so that the users can use them in a safe manner. The most important among the entire infrastructure is to standardize the symbols.

QR Code had been established as an AIM International Standard (AIM-ITS 97/01) which is a standard in the automatic identification industry in Oct. 1997. Then, it was registered in the Japanese Industrial Standards (JIS-X0510) in 1999, and was also adopted as the standard two-dimensional symbol to be used for EDI standard transaction forms in the Japanese automobile industry (JAMA-EIE001) in the same year, 1999. It has then been proposed as a standard to ISO/IEC JTC1 SC31 based on these AIM International Standard, Japan Industrial Standard, and the Japanese automotive standard code. It was specified as an ISO/IEC JTC1 international standard (ISO/IEC 18004) in 2000. Additionally, since it can efficiently handle various languages used in various countries such as Chinese characters, it has been pubulished by Guojia Biaozhun (Chinese National Standard) in 2000 (GB/T 18284), by Korean National Standards in 2002 (KS-X ISO/IEC 18004), by Tien Chuan Viet Nam (Vietnam National Standard) in 2003 (TCVN7322), and by Singapore National Standards in 2008(SS543).

Fig. 12 QR Code Standards

5-2. Application Standards Utilizing QR Code

From around 1996, considerations regarding product identification codes and transportation unit identification codes to be used for logistics had been made in the industrial area. The logistics industry uses the GS1(UPC/EAN) code and an identification code called the licence plate numbers, where GS1(UPC/EAN, JAN for Japan) symbols and interleaved 2 of 5 are used respectively. The industrial area is requiring 10-15 digits for company identification code whereas those for the retail industry require 7 digits, and 10-15 digits for product identification code whereas those for the retail industry require 5 digits – which shows that the industrial area is generally requiring more than double digits when compared with the logistics industry. The transportation unit identification code is consisted of 35 digits whereas that for the retail industry is consisted of 14 digits. Additionally, the retail industry are using numerical characters only whereas many cases in the industrial area are using alphabets. As we can see in these examples, the industrial area has been requiring more information volume including alphabets, and therefore had been actively promoting the two-dimensional symbols capable of being printed upon a smaller sapce. In 2002, electronic components labelling standard (IEC 62090) was established. IEC 62090 has accepted QR Code, Data matrix, and PDF417, but QR Code and Data matrix are being frequently used. In 2005, ISO22742 was established, whose scope of application was expanded from electronic components only which had been the case for IEC 62090 to all components / products. In 2006, the aircraft and space industrial data-product identification and traceability standard (ISO 21849) was established. QR Code and data matrix are nominated for ISO 21849. ISO 21849 also specifies the label specifications and the direct marking specifications. ISO 28219 is a standard whose scope of application has been expanded from ISO21849 to all components and products. QR Code, Data matrix, and PDF417 are accepted for ISO 28219. ISO 15394 is used for transportation unit identifications, and in the revised standard, QR Code, Maxi code, and PDF417 are being accepted.

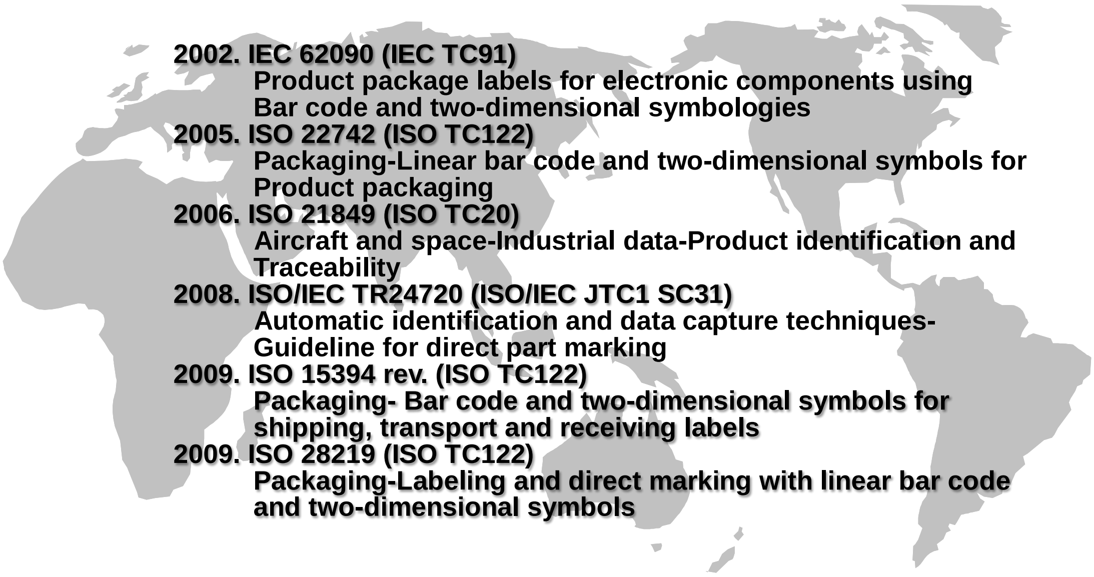

Fig. 13 Application Standards Utilizing QR Code