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OPTIONS TO USE DATA MATRIX CODES IN PRODUCTION ENGINEERING

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Abstract:
The paper deals with the possibilities of using Data Matrix codes in production engineering. We designed and tested the computationally efficient method for locating the Data Matrix code in the images. The location search procedure consists of identification of candidate regions using image binarization, then joining adjacent points into continuous regions and also examining outer boundaries of the regions. Afterwards we verify the presence of the Finder Pattern (as two perpendicular line segments) and Timing Pattern (as alternating sequence of black and white modules) in these candidate regions. Such procedure is invariant to shift rotation and scale change of Data Matrix codes. The method we have proposed has been verified on a set of real industrial images and compared to other commercial algorithms. We are also convinced that such technique is also suitable for real-time processing and has achieved better results than comparable commercial algorithms.

Key words: *adaptive thresholding, Data Matrix, Finder Pattern, Timing Pattern*

INTRODUCTION

The currently required annual growth in labor productivity requires that every business that wants to maintain market competitiveness continually improves its internal processes. Only then can be ensured that the prices of his products will not grow more than the market would accept. In addition to the price, the company must also ensure the level of customer service. In business processes, it is possible to reorganize existing activities, introduce modern technologies, use newly developed or cheaper materials for production. One way to make business processes more effective is using automatic identification.

In the business environment, it is necessary to identify inputs for production, intermediate products during production, and ultimately identify outputs. It is also possible to identify activities linked to the production or support of production, the presence of employees, etc. Man can identify objects using senses and categorize them, work with them, and so on. It can also use modern technology and use automatic identification. Modern automated identification technologies can work faster, more accurately and more efficiently than humans. It is possible to reduce process costs, speed up production processes, thereby ensuring productivity gains and gaining advantage in competition.

Goods identification has always played an important role in trading. With the first idea of automatic identification, students from the Harvard University of America came in 1932. They proposed the use of punch cards for automatic picking of goods in the store. The IT technologies had brought unlimited opportunities in the field of automatic identification. One-dimensional (1D) barcodes have been used in warehouses, cash registers, production, warehousing, property registration, parcel delivery, healthcare, libraries, and in more areas. However, one-dimensional barcodes are often insufficient to display the amount of data needed to identify the material being handled. Therefore, they are successively replaced by two-dimensional (2D) graphic codes that allow us to encode much more information in one image.

In 1984 the Automotive Industry Action Group (AIAG) published an application standard for shipping and parts identification labels which consisted of four "stacked" Code 39 bar codes. These stacked bar codes contained part number, quantity, supplier, and serial number. However it was not yet a fully-fledged two-dimensional code.

In 1987, Intermec Corporation introduced the first two-dimensional stacked barcode named Code 49 (Fig. 1a).

In 1991, Symbol Technologies introduced a 2D code named PDF 417 (Fig. 1b). In addition to common text, also graphics and programming instructions could also be encoded.

In 1994, Denso Wave developed a QR code (Fig. 1c). They were aiming to develop a code that would be quickly recognizable in the image. The QR in the name stands for quick response, expressing the development concept for the code, whose focus was placed on high-speed reading. The company has made this code available for free to be distributed and modified. The code has begun to be used in the automotive industry, but has quickly spread to other areas.

The Data Matrix code (Fig. 1d) was invented in 1994 by International Data Matrix, Inc. (ID Matrix), which was merged into RVSI/Acuity CiMatrix. This company was bought in 2005 by Siemens Energy and Automation, Inc. and in 2008 by Microscan Systems. Development of the code continued and new types emerged and began to be used in various industries. At present, this technology is still evolving and other areas of use still appear.

Fig. 1 Samples of various types of 2D barcodes

Barcodes are also used in production engineering, where various goods are stored, which is faster than physical monitoring of quantity and type of goods. Barcodes allow you to get more information at a time e.g. company and product identification, date of consumption, destination where the product is to be stored, and so on.

Several authors have dealt with barcode issues. The Data Matrix localization principle based on edge detection, on connection of the edge points with similar gradient angle and on the searching of the perpendicular regions was used in work [1], which uses the LSD algorithm to detect linear regions [2, 3]. Beside to this approach, there also other works have been published in the past, which use such as Radon transformation [4] or Hough transformation [5]. Edge detectors in image processing and object classification were also used in work [6]. Waters [7] deals with QR codes and their practical use mainly in business and marketing. Price [8] describes codes in connection with information transfer, communication, and their use in education. Karrach and Pivarčiová [9, 10] present and compare several methods for locating Data Matrix codes. Lin et al. [11] introduced a fast and straightforward method for QR code detection. [12] recognize 2D barcode using edge detection and morphological operations. Li et al. [13] proposed a method of fast code detection. Hansen and Nasrollahi [14] designed detection of barcodes in real-time using Deep Learning methods.

Nowadays, a new field of economics (Smart Specialisation) is emerging, which represents a new, growing economic specialisation, connects various industries and uses innovative technological solutions [15]. The following paper deals with the possibilities of using Data Matrix (DMX) codes in production engineering. We designed our own algorithm using modified adaptive thresholding technique, algorithm for joining the neighboring points into continuous areas, and locating Data Matrix codes in two basic steps: Finder Pattern localization and Timing Pattern verification. Part of the algorithm is also the decoding of the Data Matrix code. The proposed method has been verified on 60 Data Matrix images of laser marked codes in a metal tool and scanned by a commonly available Raspberry Pi Camera V2 camera. We compared the results of the proposed algorithm with the results of other available open-source and commercial solutions.

DATA MATRIX AND IMAGE PROCESSING

In recent years, the rapid development of practical applications for image processing and analysis has clearly been seen. In the car making industry, pharmaceuticals, police and armed forces, automated manufacturing and measuring systems, a variety of image processing systems are widely used. The subject of development in this area is the effort to transfer the ability of human vision to electronic perception and understanding of the image. The goal in computer vision and image processing is to determine whether the image data contains or does not contain a particular object, feature, or activity. Nowadays, the best algorithms for solution of such tasks are based on neural network. Their performance is close to the abilities of people. Using modern computer vision systems, it is possible to control robots, sort products, estimate quality and damage of products. Computer vision systems are not only replacing manual control but improving it.

Computer vision offers new possibilities to use Data Matrix codes, which are often used in storage, production, distribution and sales processes to identify items. The possibility of using Data Matrix codes is, for example, in the industrial designation of products for their identification and tracking in the production process and subsequent use or storage. Data Matrix codes also make easier control of individual objects in the production process. Different products are produced on the same production line and codes are used to identify them. E.g. in the car making industry, four and six-cylinder engines are assembled on the same assembly line. Codes serve to convey the correct components so that they arrive at the correct time on the assembly line. Codes are popular for their ability to store a relatively large amount of data on a small place. The code may include the type and serial number of the product, the number of packages, the date of manufacture or expiry, the batch number, and the like. These codes have an advanced error checking and correcting mechanism, so they are legible even in case when the code is partially damaged.

Data Matrix is an ISO standard and is used by many industry organizations as the industry standard. It is expected to continue to be exploited and improved mainly in terms of technology. The development is leading to more and more automation, and Data Matrix codes are a suitable way to this goal. The advantage is that it is licensed as a public domain.

The rapid development of mobile phones and their massive use has further expanded the possibilities of using 2D codes. A regular camera on a mobile phone with a freely accessible mobile application allows you to capture 2D codes, even from a display or monitor. This ability is already commonly used, for example, for fast mobile phone access to websites, easy Wi-Fi connection, fast loading of business cards without manual input, marketing, advertising or marking of different objects. E.g. in Germany, Data Matrix codes are often placed at monuments and contain a direct link to website which contains information about such place.

METHODOLOGY OF RESEARCH

For scanning the codes which are part of an image in industrial world we have designed and tested a computationally efficient method for locating the Data Matrix codes in the images. The proposed Data Matrix code localization method uses typical Finder Pattern and Timing Pattern patterns, local thresholding, connection of adjoining points into continuous regions and external region boundaries.

We also proposed a modified computing efficient adaptive thresholding technique that uses local local mean and variance under the sliding window. The proposed method has been verified on a test set consisting of 60 samples of DMX codes marked with laser on metal tools, which were scanned by a Raspberry Pi Camera V2 camera. Samples of Data Matrix Codes are shown in Fig. 2.

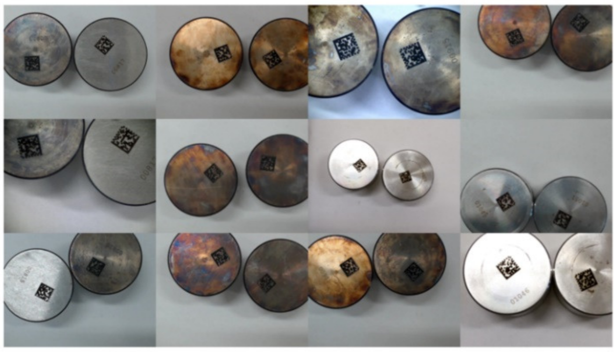

Fig. 2 Data Matrix code samples laser-marked in metal

The proposed algorithm for location of the Data Matrix codes in the images is shown in the flowcharts in Fig. 3a-3d

Firstly we transform the input image into binary form and then we filter out objects, which couldn't be Data Matrix code (area of connected region is too small or aspect ratio is not in the range (0.5-2.0)).

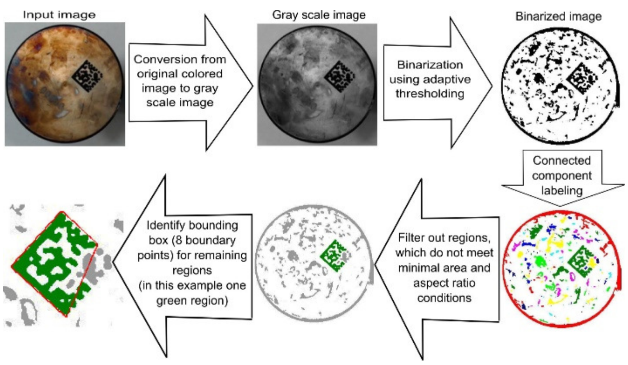

Fig. 3a Flowchart for the first phase: raw location of Data Matrix codes in images

Next we locate the Finder Pattern on outer boundaries of regions (objects) identified in prior step.

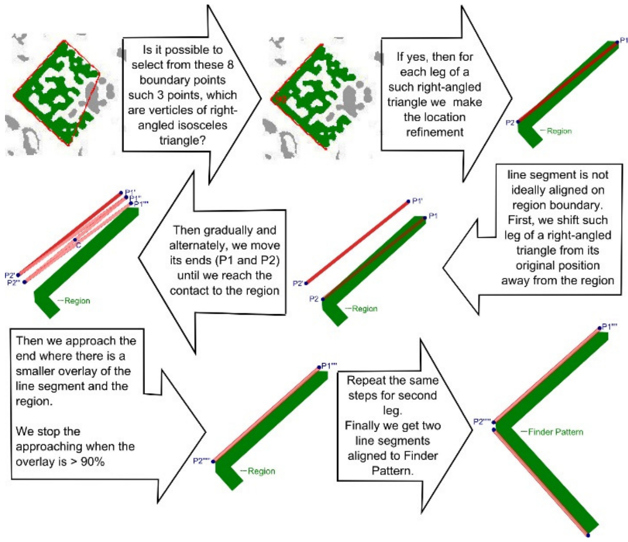

Fig. 3b Flowchart for the second phase: location of Finder Patterns of Data Matrix code

Once we have identified two sides of bounding rectangle, we must verify than Timing Pattern is presented on two opposite sides of the Finder Pattern.

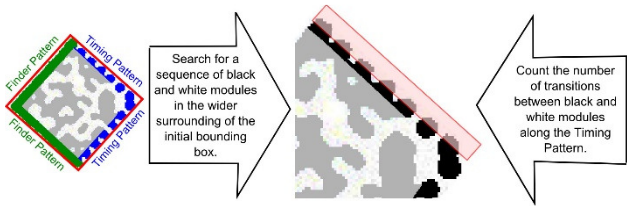

Fig. 3c Flowchart for the third phase: verification of Timing Patterns of Data Matrix code

And finally we decode binary matrix of Data Matrix code into textual representation.

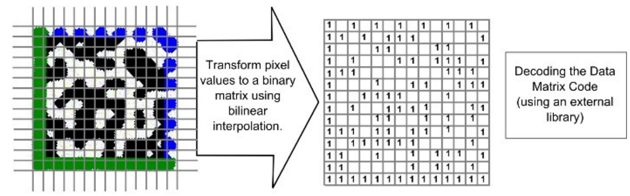

Fig. 3d Flowchart for the last phase: decoding of Data Matrix code

RESULTS OF RESEARCH

We designed and tested the computationally effective method for locating the Data Matrix codes in the images. This method is also suited to real-time processing and has been verified on a set of images taken from real world. The suggested method uses typical Finder Pattern and Timing Pattern, local threshold values, connecting of the points into continuous regions and outer region boundaries.

The results of the proposed method were compared with the results of other available open-source and professional algorithms:

- Google ZXing (open-source) [16]
- OnBarcode .NET Barcode Reader [17]
- Dynamsoft Barcode Reader SDK [18]
- Leadtools Data Matrix SDK [19]
- Inlite Barcode Reader SDK [20]
- Libdmtx (open-source) [21]

In Fig. 4 is a comparison of the results of our proposed method with the results of other algorithms.

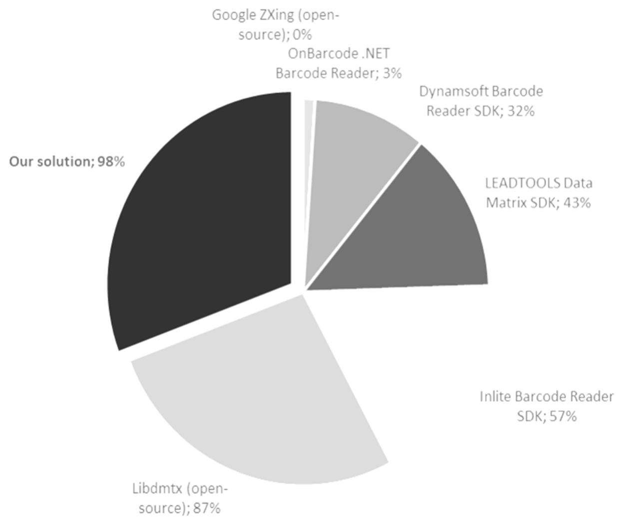

Fig. 4 Comparing the results achieved with the results of other authors

As can be seen from Fig. 4, from the algorithms we tested, we have the best results when our algorithm recognized up to 98% of the Data Matrix Codes (59 out of 60), unlike the other solutions that recognized less Data Matrix Codes. The Libdmtx (open-source) algorithm recognized 87% Data Matrix codes. The worst results are Google ZXing (open-source) – 0% and OnBarcode .NET Barcode Reader – 3%.

DISCUSSION

As can be seen from Fig. 4, our solution has outperformed competitive solutions. We tested competitive software using default settings, mostly by using an on-line decoding service that does not allow us to set or tune recognition parameters. Surprisingly, Google ZXing was unable to decode any of our test Data Matrix codes. Perhaps the results of competing software would be better if we were able to tune-up the recognition parameters. However, most competing decoders have closed sources and therefore we cannot compare their detection algorithms in detail or set-up their parameters.

We assume that our proposed algorithm achieves better results than the algorithm being compared, mainly because of the use of a local thresholding and our invariant search of the Finder Pattern and the Timing Pattern in the image, regardless of their location.

Our proposed algorithm uses for conversion of a grayscale image to a binary image a modified adaptive thresholding technique. This is a computationally efficient technique that uses local mean and variance under a sliding window. In a binary image represent one bit the information about the point in the image (0 – background, 1 – foreground). The standard adaptive thresholding technique calculates an individual threshold value for each point in the image. Threshold value is calculated as the average intensity of points under the sliding window. To speed-up the threshold calculation, we have used pre-calculated integral sum image and the global threshold value.

$$B(x,y) = \begin{cases} 0 \leftarrow I(x,y) > 150 \\ 0 \leftarrow I(x,y) >= T(x,y) \\ 1 \leftarrow I(x,y) < T(x,y) \end{cases}$$
$$T(x,y) = \left(\frac{1}{961} \sum_{i=-15}^{15} \sum_{j=-15}^{15} I(x+i, y+j) \right) - 10 \quad (1)$$

As an alternative to adaptive thresholding, iterative global thresholding can be used, where the threshold value is increased in each iteration (we used 8 iterations starting with a threshold value of 30, which is increased by 10 in each iteration).

The most common causes of localization failures were the structural defects of the material on the surface of the tools that caused the reflection of light and consequently the failure of the local thresholding. These errors also caused the discontinuity of the areas and thus also the incomplete identification of the Data Matrix in the image. As a solution to overcoming these issues, we have improved local thresholding (Eq. 2). This technique, unlike the commonly used Niblack and Sauvola techniques, does not require a square root calculation for each point to calculate a standard deviation and is less sensitive to the selection of parameters.

Our proposed modified local thresholding technique, which combines the intensity of the point, local mean and deviation under the sliding window, calculates the local threshold value according to:

$$T(x,y) = m(x,y) - \frac{I(x,y)}{k_1} - \frac{s^2(x,y)}{k_2} \quad (2)$$

where:

$m(x, y)$ – local mean,

$s^2(x, y)$ – local variance of the pixels under the sliding window,

k_1 – constant controls penalization of bright points (DMX code in image is the darkest object),

k_2 – constant controls decreasing of local threshold for points in which neighborhood intensity significantly varies.

This technique has achieved significantly better results in special cases that we have to solve than classical local thresholding technique that use only local mean and delta constant.

Since the algorithms being compared were mostly commercial and therefore closed source, the algorithm or techniques they use are not known. We assume that Google ZXing (open-source) and OnBarcode .NET Barcode Reader only decode the non-rotated Data Matrix codes in the base position, which is the cause of a low success.

Our algorithm has achieved better results by being invariant to rotation, shifting, and scale changes, and searches for the Finder Pattern and Timing Pattern, regardless of their location.

We have made further improvements by identifying and verifying that image resolution has an impact on recognition, and we have also shown that iterative image resizing and subsequent recognition can further improve results. In the first test, we used the original image size (i.e., 100% of the original size) and if we failed to locate and decode the Data Matrix code, the image was resized to 75% of the original size, and we repeated localization. With 100% size, material errors were highlighted, and the Data Matrix code was not correctly recognized. After shrinking the image to 75%, we've got a smoother image and we've got better results.

CONCLUSION

At present, a regular user can meet 2D barcodes in three areas. The first is consumer goods: food, drugstore, pharmaceutical products. The second is mass transport and mail services. In these areas, the codes do not belong to the end user but to the manufacturer or carrier's needs. The third area is advertising and marketing actions.
In production engineering, Data Matrix codes can be used to designate logistic units, parts, warehousing positions, but also to navigate automated robots [22, 23, 24, 25]. Due to their low cost, accuracy, speed, reliability, flexibility and efficiency, as well as the ability to record large amounts of data on a small area, they still have a great advantage in industrial applications. Identification is an important part of business processes. As the Data Matrix codes allow the automatic identification, an enterprise can use a variety of technologies which help innovate and make more effective business processes, reduce costs and improve service levels. If you put into real operation and when using automatic identification, you must adhere to the principles such as correct code size, appropriate code placement, careful testing on various devices and platforms, and so on. Actual efficiency is very much declining with every little mistake the company will do and will ultimately affect the end result.
We designed and tested the computationally effective method for locating the Data Matrix codes in the images. The proposed method uses typical Finder Pattern and Timing Pattern patterns, modified local thresholding technique, connecting points into continuous regions, boundaries of the outer region. The proposed method has been verified on a real-world test set and compared to competitive solutions. Experimental results show that our method has achieved better results in our case than commercial solutions.
Our solution is suitable for real-time processing, allows automatic processing and evaluation without operator intervention, does not require extensive pre-processing, eliminates the position of the Data Matrix in the image (shift, rotation, scale), partially compensates for code deformation (light reflection, incomplete code) and image quality.

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