Reliability of Barcode Detection

František Duchoň, Peter Bučka, Martin Dekan, Andrej Babinec

Slovak University of Technology, Ilkovičova 3, 812 19 Bratislava, e-mail: frantisek.duchon@stuba.sk

Abstract: This article deals with the common detection of barcodes well-known at these days - both linear and two-dimensional. The main part of the article consists of experiments with factors that affect the overall success of barcode detection. The goal is to highlight some of the rules for setting up barcode applications. Frequently, the false impression originates that this problem can be eliminated by applying commonly available libraries. Therefore, factors influencing the success of barcode detection are thoroughly analyzed in this paper.

Keywords: Barcode, reliability, detection

1. INTRODUCTION

The expanding of industry since the 17th century led to the need for product labeling, cataloging, data archiving and identification. The situation has gradually begun to improve by the end of the twentieth century with the introduction of barcodes and afterwards also with other identification technologies such as QR codes or RFID tags. One-dimensional barcodes have begun to be used in shops where they should facilitate and accelerate work with the merchandise at the cash desk. They were designed in the form of discs consisting of lines with different widths (Fox, 2012). In 1971, the Uniform Grocery Product Council acclaimed to present designs with a chosen structure consisting of a 10-character code. The winner was the IBM design and afterwards the introduction of Universal Product Code (UPC) code as the standard for the labeling of goods was presented in (Kato et al., 2010).

The barcode is a one-way form of information entry. The information is encrypted in an image that consists of placed alongside binary lines with a fixed width. Barcodes consist of a unique start and stop character, data characters, and blank spaces before the start and stop characters, called quiet zone (Kato et al., 2010). In addition, besides the data itself, other information can be also included in the line form. For example, checking the correctness of information importing or the beginning of the code can be included. Behind the barcode is usually a legible entry, which is intended if the scanner is unable to read the code and should be entered manually in the information system.

Multiple technologies are used to read barcode data. All of them have a common character. They are based on the optical principle. Some of them are passive and use the ambient light to read the code. Others use their own light source to improve code readability or use a laser beam.

The type of scanner with the simplest design is in the form of a writing pen and its title comes from it – pen scanner. It has a simple construction. The scanner body has one or more glow diodes that provide sufficient barcode lighting to identify lines and gaps (Carolina Barcode Inc., 2018). Its control unit processes the reflected light intensity from a receiver that is a photosensitive semiconductor element. Based on changes in the intensity of the received light, the control unit is able to recognize the changes of black and white in the barcode (Kato et al., 2010). The pen scanner is prone to the non-steady pen movement speed through the barcode. In such a movement, the system is unable to correctly recognize the width of the lines in the code, and thus cannot decode the information contained therein.

Another reader device representative is a CMOS scanner. It works on the same principle as a pen scanner. Its main advantage is scanning the entire width of the code at once. The code can also be enlightened by its own light source. Its reflection from the scanned code is returned back to the device where it passes through the optics. Consequently, this optics modifies the image (Carolina Barcode Inc., 2018). The array of photosensitive semiconductor elements is used as a receiver. The reflected light hits this array. The intensity of the reflected light, when attaching the scanner to the barcode, is also different as well as using the pen scanner. The intensity depending on whether the light reflects from the white or black color. This type of scanner is often used in cash systems, warehouses and logistics courier services (Datalogic S.p.A., 2017) because of its small size and possibility to produce it in the form of a portable version.

Moreover, laser scanners are commonly used. Detection and identification of the code is ensured by the photosensitive receiver where the reflected beam hits. The part of the laser energy is absorbed by the surface from which the beam is reflected. The intensity of the reflected beam that reaches the receiver, determines whether the beam is reflected off the white or black surface. This type of scanner is for its benefits often used in supermarket cash systems. It is usually incorporated into a cash desk, but moreover there are also small manual versions of this type (Datalogic S.p.A., 2017). The scanning speed is up to more than 1,000 readings per second (Barcodes Inc., 2013). It is also suitable for industrial use to identify products in the production. Its main advantage is scanning speed and low percentage of error during reading the code and low cost compared to the image scanner, as well (Camcode Durable Barcode Solutions, 2017) .

Nowadays industry-leading scanners based on industrial cameras are being used very frequently. Their advantage in an industrial environment is that they can handle multiple tasks at once. One of these may be detection of barcodes or other codes and, simultaneously they can detect, for example, product defects or they can measure object dimensions (Omron Microscan, 2018). To speed up image capturing, cameras are equipped with a backlight to provide enough reflected light to fit into the scanning chip. This can increase the shutter speed of the camera lens. The advantage of such a system is its variability. It can also be installed in a limited space for its small dimensions. It allows capturing real-time one-dimensional, two-dimensional and multi-dimensional matrix codes (Barcodes Inc., 2013). It has better readability of damaged codes and in some cases with unfavorable scanning conditions it is not possible to replace it by laser system. Its disadvantage over the above-mentioned technologies is the demand for image processing hardware, and hence the slower code scanning speed (Barcodes Inc., 2013).

2. SYSTEM CONFIGURATION

The Avigilon 2.0-H3-B2 IP Camera (Fig. 1) was selected as the image processing camera. The camera has installed a motorized lens with remote control of zoom and image sharpening. The lens parameters are 3-9 mm, F1.2. The camera can capture the 35° - 98° width of scene. The maximum resolution of the camera is 1920 points horizontally and 1080 points vertically. The power supply to the camera can be a 12V DC or PoE (Power over Ethernet) source. The camera is installed on a standard tripod used in security applications.

Fig. 1. Avigilon 2.0-H3-B2 Camera.

3. FACTORS INFLUENCING THE RELIABILITY OF DETECTION

3.1 Image Resolution

One of the most important factors influencing the reliability of barcode detection in the image is the resolution of the scanner device and the barcode size. The principle is to define the minimum resolution of the camera where the barcode can be detected. Codes need to be scanned from different distances to verify and detect these values. When the application loses the ability to detect these codes, mentioned values will be recorded. For a one-dimensional EAN13 code, a resolution with a minimum of 1.5 pixels wide at the narrowest segment is required for reliable detection. For a two-dimensional QR code, it is at least 2.6 pixels for the smallest segment (Fig. 2).

Fig. 2. Demonstration of the minimum resolution for barcode at the reliable detection limit.

The use of such values is possible but not appropriate. During their reading more frequent malfunctions and inaccuracies can originate. These values are valid only to horizontally positioned barcodes. Measurement of code readability was performed with scene lighting of intensity in the range of 500 to 1300 lux, which represents a sufficiently illuminated scene. For the purpose of determining the location of the camera, it is possible from this data to calculate the maximum distance from the read code of known size. Therefore, for this purpose, a several camera parameters, the size and the type of read code need to be identified. The following tables (Tab. 1, Tab. 2) show the minimum steady readable resolutions for the multiple single and double dimensional tested codes. The parameter Code Width indicated in pixel units means the minimum readable code width in the image where its width covers a given number of pixels. The parameter Bars per Code Width indicates how many parts (white or black) the code width is composed of. The parameter Pixels per Bar is the ratio of the previous parameters. It is also given in pixel units.

Table 1. Minimum number of pixels per bar in EAN13 code

Data	Code Width [pix]	Bars per Code Width	Pixels per Bar
4337185220586	133	95	**1.40**
8594739212756	137	95	**1.44**
8588000014347	131	95	**1.38**
8588004071100	129	95	**1.36**
7680522540272	127	95	**1.34**
5900951127748	124	95	**1.31**
8593893713673	137	95	**1.44**
8588000032549	133	95	**1.40**
4040883500002	129	95	**1.36**

Table 2. Minimum number of pixels per bar in QR code

Version	Code Width [pix]	Bars per Code Width	Pixels per Bar
V.2	59	25	**2.36**
V.2	59	25	**2.36**
V.1	52	21	**2.48**
V.2	58	25	**2.32**
V.3	75	29	**2.59**

A different data are valid for the codes that are not placed horizontally compared to the camera. For a one-dimensional EAN code, this is 1.8 points per bar, and for a 2-dimensional QR-type code it is 2.6 image points per pixel. In order to improve especially read-out of the rotated codes, it is advisable to use image transformation by turning it. This will increase the reliability of code detection. Image search is a computationally demanding operation. Therefore, a 15 ° step was selected in the proposed algorithms. This has increased the reliability of code detection even in badly positioned codes whose height does not allow them to read in the horizontal or vertical direction.

Fig. 3 shows the rotation in 15° intervals. The upper row of the pictures is at the bottom of the detection range. In the bottom row there is a situation that improves code detection. This code is not located horizontally or vertically and it has a small height. In case, the computer running the application does not have the necessary means, problems can arise, for example, with the image processing speed. To avoid this problem, it is possible to parallelize the solution and process each rotation separately.

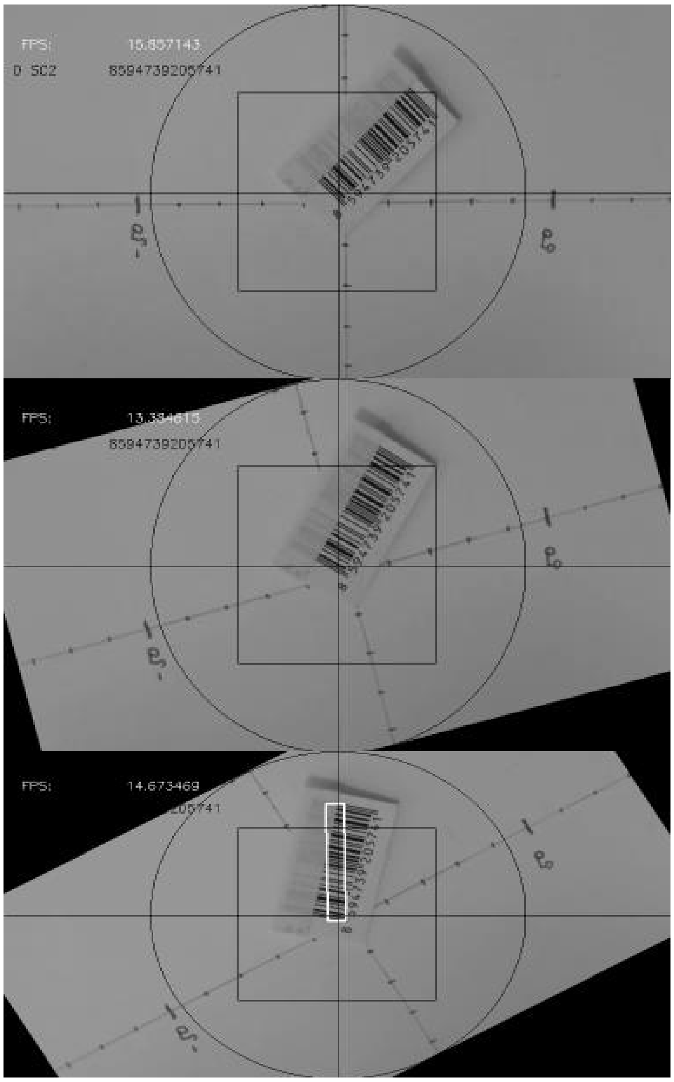

Fig. 3. Increase of probability of barcode detection by introducing rotated image detection.

Several measurements, evaluated in the table, were made to quantify the probability of incorrect code-in-picture identification. Some parameters have been changed between measurements. For the evaluation, 1000 scans of the scene were used for two different camera resolutions and two code distances. 5 barcodes were scanned at the resolution of 1280x720 pixels, and 6 barcodes were scanned for the resolution of 1920x1080 pixels. Ideally, the output should have 5000 or 6000 read codes. Measurements (Tab. 3, Fig. 4) were made for two distances of plane position with codes from the camera, specifically 35 cm and 46 cm.

From the Tab. 3 it results that the reliable detection is given by the properly chosen distance of code from the image, or the selection of appropriate camera resolution. It is interesting to note that with the high camera resolution together with the small distance of the code, more false detections are produced. After reviewing the data, it turned out that it was a badly scanned code.

Fig. 4. Scanned scene used in the measurement of success of the code detection.

top left - Measurement 1 [1280x720 pixels; 35 cm]
top right - Measurement 2 [1280x720 pixels; 46 cm]
bottom left - Measurement 3 [1920x1080 pixels; 35 cm]
bottom right - Measurement 4 [1920x1080 pixels; 46 cm])

Table 3. Measurement of the success of code detection in the image depending on the resolution of the camera and the distance from the camera

Measurement Serial Number	1	2	3	4
Number of codes in the image	5	5	6	6
Number of Images	1000	1000	1000	1000
Distance [*mm*]	350	460	350	460
Resolution [*pix*]	1280x720	1280x720	1920x1080	1920x1080
Found Codes	4996	3152	6110	6010
False Detection	2	284	110	10
Correct Detection	4994	2868	6000	6000
Detected Code	6	2132	0	0
Operation Length [*min:s*]	3:49	2:36	4:18	4:00

3.2 Image Distortion

The image from the camera contains the geometrical distortion caused by the light transition through the camera lens. Distortion is expressed by the object deformation in the image captured by the camera. It is expressed mostly at the long vectors or lines that are deformed to curves. It occurs in two ways. The positive image distortion deforms the line to the center of the image and the negative image distortion deforms the line from the center (Pavlovičová and Loderer, 2016).

The most common case is a negative image distortion caused by a lens, also called the fish eye effect. The solution to this problem is to use the pinhole camera model and to scan the object with known parameters (Pavlovičová and Loderer, 2016). The object found in the camera image is compared with the parameters of the known model and afterwards the lens distortion is specified. The equation is created for each scanned pattern. Based on these equations, the sought camera parameters with the shape of two matrices are calculated. One matrix is the calibration matrix of the camera parameters and the second matrix is the distortion matrix (Pavlovičová and Loderer, 2016).

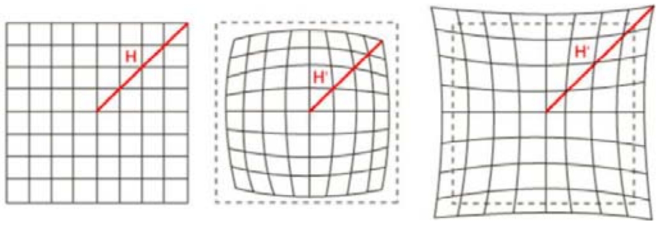

Fig. 5. Image distortion (left - non-distorted image, in the middle – negative distortion, right – positive distortion).

Calibration matrix of the camera is defined:

$$\begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

Where f_x and f_y are focal length of camera in axis x and y. Parameters c_x and c_y represent origin of the coordinate system, which within the ideal objective is in the middle of image. However, due to asymmetric lens design it is deviated.

Distortion matrix is defined:

$$[k_1 \quad k_2 \quad p_1 \quad p_2 \quad k_3]$$

Where k_1, k_2, k_3 are coefficients for radial distortion, and p_1, p_2 are coefficients for tangential distortion. These coefficients affect the coordinates of image points (Fig. 6):

$$x_c = x(1+k_1r^2+k_2r^4+k_3r^6)$$
$$y_c = y(1+k_1r^2+k_2r^4+k_3r^6)$$
$$x_c = x + \left(2p_1xy + p_2(r^2+2x^2)\right)$$
$$y_c = y + \left(p_1(r^2+2y^2) + 2p_2xy\right)$$

In the model of distortion, point A is an ideal position of image point, and point B is its distorted position. Using the calibration and distortion matrix output image should be improved and the distortion should be removed.

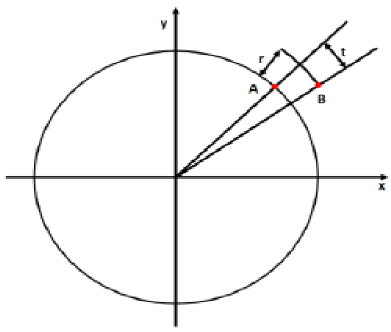

Fig. 6. Model if image distortion.

In order to determine the impact of the camera's calibration (Fig. 7) on the code detection some experiments were made. They were made to determine whether or not is the elimination of distortion beneficial to the code detection. The attempted scanned scenes were set at the limit of code readability and simultaneously outside the center of the image. If the loss of part of the image is omitted in order to eliminate the distortion and simultaneously the loss of information presented in this part of the image, the result is that the distortion removal in the one-dimensional codes brought degradation of the detection capabilities and in two-dimensional QR type codes brought improvement.

Fig. 7. Change of the detection capability after the distortion removal (left - without distortion, right - with eliminated distortion).

Changes in the detection reliability, however, were not essential. They only appeared at the limit of detection capabilities. Enhancement of detection caused alignment of the read QR code. After the code was aligned, consequently it was enlarged in an x-axis and its readability was improved. Degradation of detection in one-dimensional codes is due to software image transformation, which causes it to blur even in the x-axis direction. This blur causes the loss of step change transitions between the white and black parts of the code. Image transformation uses an input image (function), a camera parameter matrix, and a distortion coefficient vector to eliminate distortion. The function creates maps using camera parameters and distortion coefficients, based on which the positions of all the input image points are recalculated (PC Magazine and PC PCMag.com, 2018). Subsequently, they are drawn to the new positions using bilinear interpolation. The principle of bilinear interpolation is to determine the value of the resulting pixel $\widehat{f_c}(x, y)$ using the weighted average of the surrounding pixel values (Fourcc.org, 2018). The weighting is given by the position of a particular pixel and its location in the calculated map. The calculation of the interpolation using the four adjacent points is given:

$$\widehat{f_c}(x,y) = (1-\Delta_x)(1-\Delta_y)f(n_1,n_2) +$$
$$+(1-\Delta_x)\Delta_y f(n_1,n_2+1) +$$
$$+\Delta_x(1-\Delta_y)f(n_1+1,n_2) +$$
$$+\Delta_x\Delta_y f(n_1+1,n_2+1)$$
$$\Delta_x = \frac{(x-n_1T_1)}{T_1}; \Delta_y = \frac{(y-n_2T_2)}{T_2}$$

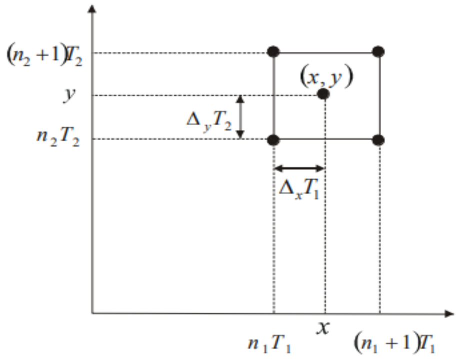

Fig. 8. Principle of bilinear interpolation (Fourcc.org, 2018).

The final image is affected by this interpolation, i.e. during new pixel values calculation it occurs a loss of details, particularly step change of brightness caused by blurring. Bilinear interpolation behaves as low-pass filtering (Fourcc.org, 2018). Its application is not uniform on the whole image, and is most evident in the marginal parts of the image or in the parts of the image most affected by image distortion. Elimination of image distortion is a computationally demanding function. This is particularly important for the application's FPS. For reading and processing of barcodes, the scanning frequency has a high priority and therefore it is not appropriate to remove the distortion. Fig. 9 shows the relation between the image processing speed and the image resolution. However, removal of distortion is important, for example, in detecting the position of the code in the space.

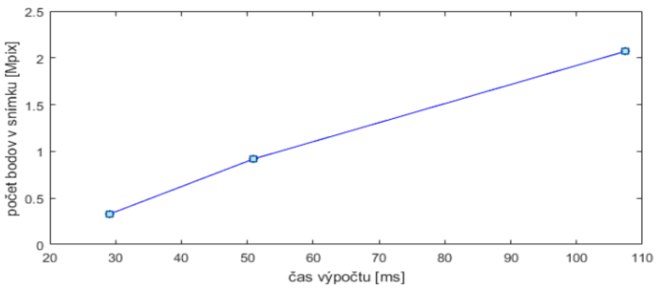

Fig. 9. The effect of the number of pixels on the calculation time.

3.3 Light Conditions

Intensity of scene lighting can fundamentally affect the ability to recognize codes in the image. The necessary intensity of lighting is also closely related to the capabilities and settings of the camera. In commonly available cameras, it is possible to set several parameters for light processing. The number of these settings, their functionality and the ability to deal with complex lighting conditions depend on the manufacturer of the particular camera model and typically on the price of the device.

For this work, the Avigilon 2.0-H3-B2 camera has been used. It belongs to the middle class because of its parameters and has a fairly wide range of settings. The settings that the camera has and at the same time can influence code recognition under different lighting conditions are Exposure, Night/Day Mode Filter (IR Cut Filter). The exposure time of the image has the most significant impact on sharp image capture. It is strongly dependent on the amount of light that is reflected in the camera lens by the scanned scene. Quantification of the values of the required light intensity is complicated. Value is dependent on multiple factors and cannot be generalized. The most important factors for selecting a light source and its intensity are the estimated size and type of code in the image, and the speed of its motion in the image.

For example, for an EAN code that occupies a width of 149 pixels in the image, a minimum of 1.5 Lux with a set shutter value of 160ms is required for stable readings, and the code has to be without movement in the image during the reading. Such settings are at the limit of the camera's capabilities and are unsuitable for use. In general, the better the scene is illuminated, the faster it can be scanned. And the object where the code is located can move at a higher speed. The lighting of the scene must be uniform and should not come in one direction only.

Fig. 10 illustrates the effect of light reflection on the ability of application to detect the codes. Codes are printed on materials that differently reflect the light. In the figure on the left, one inappropriately placed light source is used and in the figure on the right either the second (less powerful) light source is used to change the light conditions. In practice, ring-shaped lighting is used placed around the camera lens or multiple sources of light located on the sides of the camera.

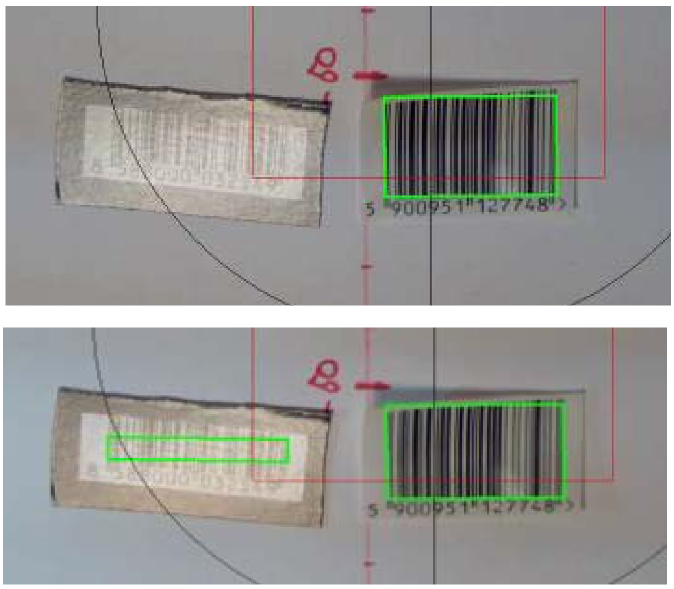

Fig. 10. Effect of light reflection on detection.

3.4 Motion in the Picture

Another factor influencing code detection is its motion in the image. To verify this effect, a series of attempts have been made to find the maximum possible speed of code movement in the scanned scene. Two bar codes were placed on the periphery of the rotary disk. One was placed in the horizontal and the other in the vertical direction to find out the direction of code rotation relative to the direction of the movement. The camera was set to the minimum shutter release time and the scanned scene was illuminated by a 7800 Lux lamp at a distance of 15 cm from the code reading point. After several testing attempts in motion, it was shown that the most significant impact on the success of code acquisition is the scanning frequency. To test the ability of the application to read the codes in motion, several measurements were performed at the different rotational speeds of the disk.

Table 4. Successful detection of moving code

Speed of Code Movement [m/s]	Rotational Speed [Hz]	Horizontal	Vertical
0.5	0.44	> 95 %	> 95%
1	0.88	> 95 %	60 - 80%
1.5	1.32	> 95 %	30 - 50%
2	1.76	> 95 %	< 10%
2.5	2.2	< 40 %	0%
3	2.64	0%	0%

Only correctly scanned codes are included in the Tab. 4. The table shows that the application can better read the codes which are also placed horizontally due to the horizontal direction of movement. At higher speeds, there was a problem with image deformation, also called *Rolling shutter effect*. This effect originate due to the fact that the scanned image is read with scanner sequentially down the rows. Each time a row is loaded, a short time shift occurs. This shift, in the case of the dynamic scene, can be known that the bottom of the image outrun the top in the direction of object movement, and thereby deforms the image. Shift of the image can be compared between the Fig. 11 and Fig. 12.

This deformed barcode can no longer be read in the vertical direction. In the case of a horizontally placed code, the row is read without deformation, when reading each row where the code is placed. At speeds above 2 m/s (Fig. 11), the success of code detection started to decline also with a horizontal placed code and at a speed of 3 m/s (Fig. 13) it was no longer readable at all.

This was caused due to the fact that the moving object began to lose its sharpness; it was not possible to detect the edges and the transitions between the dark and the light part. The figure shows clearly that in the right part of the scanned code, the app does not have a chance to identify the last lines in the code because they are merging together into one gray line. Removing this effect from the image is not possible with a standard image processing method and should be counted at higher speeds. Changing the camera type would remove the problem if the camera was equipped with a mechanical shutter instead of an electronic one. By these tests, only the limit detection capabilities of moving code in the image were examined.

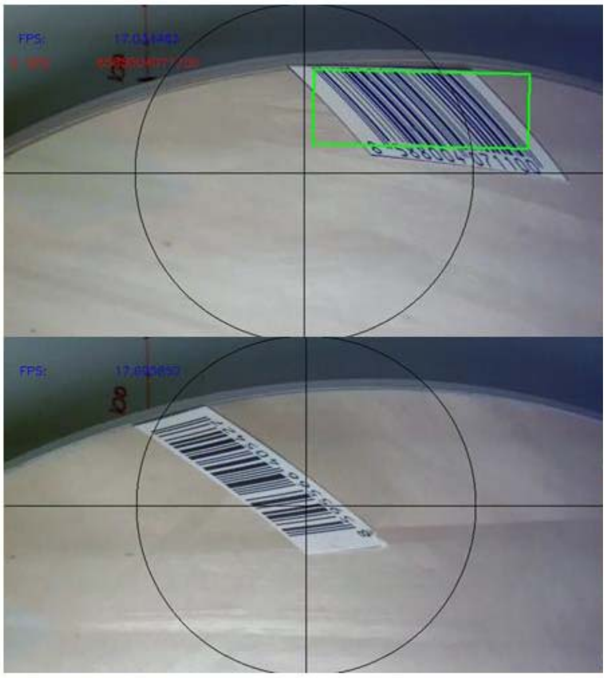

Fig. 11. Rolling shutter effect – dynamic scene images with 2 m/s rotating object.

Fig. 12. Rolling shutter effect - static image.

Fig. 13. Image blur due to the motion (3 m/s code movement speed).

3.5 Code Coruption

Factors influencing the reliability of detection include the print quality of the code, the material where the code is written with its properties, as well as possible code corruption. Some codes types have a built-in correction to reconstruct the corrupted code. For a one-dimensional code, it is especially true that its corruption does not have to completely remove one of the code segments. In practice, this means that the code must have a legible whole character field that can be overlapped by one line. The height of this part of the code does not matter, and simultaneously it must be possible to read the code in a horizontal or vertical direction. The exception is in the case of code rotation.

In Fig. 14 it can be seen that even relatively extensive code coverage does not reduce the ability of the application to detect it. In the case of image in the middle row on the right, the last part of the code is hidden, so the last character cannot be read. As a result, it is not possible to specify the string that contains the code. The last two images show the code corrupted with lines that makes it difficult to read.

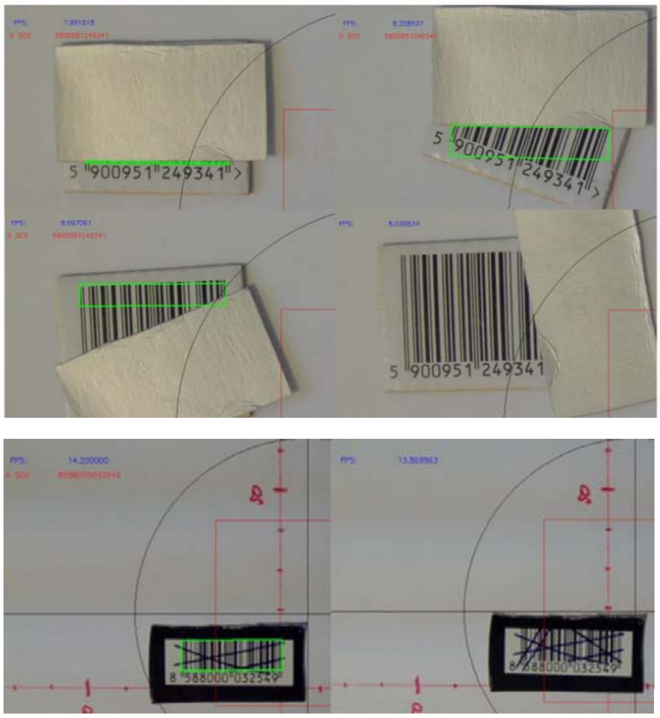

Fig. 14. Simulation of various corruptions of one-dimensional code.

With two-dimensional codes, the situation is different. It is possible to incorporate the correction of damaged parts of the codes. As can be seen in Fig. 15, this QR code correction can have the reconstruction ability up to 30% of the total code area.

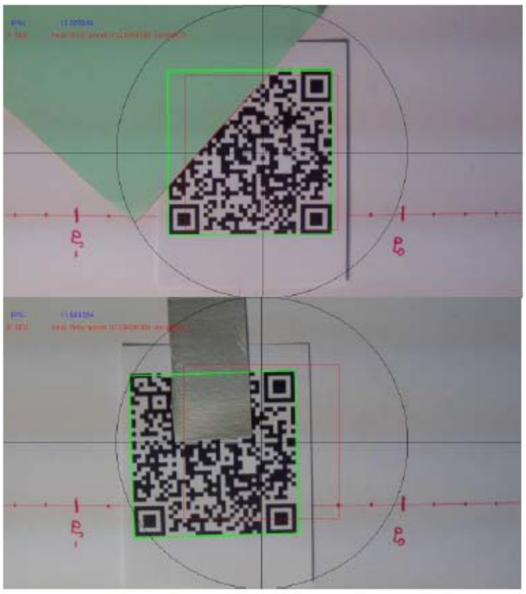

Fig. 15. Demo of damaged QR code correction.

The value of the damage correction capability must be set during the producing of given code already. Introducing a QR code correction it can result in an increase of its version and hence in a larger covering area.

4. CONCLUSIONS

The most important factors influencing the success of barcode detection are undoubtedly the effects of camera resolution, image distortion, light conditions, image movement, and code corruption. Each factor can therefore significantly reduce the reliability of barcode detection. Sometimes it can reach a total failure of the read. All factors must be set before creating the application itself. This can lead to significant savings, for example, preventing camera exchange due to the insufficient resolution, and similarly.

ACKNOWLEDGEMENT

The paper was created with support of projects VEGA 1/0065/16, VEGA 1/0752/17, APVV-16-0006, and company TSS Group a.s.

REFERENCES

Barcodes Inc. (2013) Evaluating Barcode Reading Technologies: Laser vs. Imager. Available at: *https://www.barcodesinc.com/news/?p=8095* (accessed 19 September 2018).

Camcode Durable Barcode Solutions (2017) Barcode Scanner Buying Guide: How to Choose a Handheld Scanner. Available at: *https://www.camcode.com/barcode-scanner-buying guide.html* (accessed 19 September 2018).

Carolina Barcode Inc., How Barcode Scanners Work. Available at: *https://www.carolinabarcode.com/how-barcode-scanners-work-a-69.html* (accessed 16 April 2018).

Datalogic S.p.A. (2017) Product overview. Available at: *https://www.datalogic.com/eng/products-hp-16.html* (accessed 23 January 2018).

Fourcc.org, Video Codecs by FOURCC. Available at: *https://www.fourcc.org/codecs.php* (accesed accessed 23 January 2018).

Fox M (2012) N. Joseph Woodland, Inventor of the Bar Code, Dies at 91. Available at: *http://www.nytimes.com /2012/12/13/business/n-joseph-woodland-inventor-of-the-bar-code-dies-at-91.html* (accessed 12 December 2018)

Kato H, Keng TT and Douglas C (2010) Barcodes for Mobile Devices. *Cambridge : Cambridge Univerity Press*.

Omron Microscan (2018) Omron Microscan Systems. Available at: *http://www.microscan.com* (accessed 16 April 2018).

Pavlovičová J and Loderer M (2016) Pavlovičová J and Loderer M (2016) *Digital Image Processing. Bratislava: FELIA s.r.o.*

PC Magazine and PC PCMag.com, Definition of: Windows Media formats. Available at: *https://www.pcmag.com/encyclopedia/term/54661/windows-media-formats* (accessed 16 April 2018).