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# A readability analysis for QR code application in a traceability system

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ABSTRACT

Traceability of data through transformation stages of each individual food product, starting from raw products and to the final product, as well as printing the key data on the product package, adds to the consumers' trust in product quality. For each food product, it is necessary to track data starting from the stage of raw products farming, through food processing, transport, warehousing, to retailing and reaching the end consumer. In order to allow insight to the key data to the user (mostly end consumer), this paper suggests recording the data on the product package in the form of a quick response two-dimensional barcode (QR code) in key points of the product's life cycle. For efficient functioning of the proposed system, it is essential to ensure fast and reliable operation through proper placement of the QR code on the package during production, and fast and easy data reading by the product consumer. This paper presents the results of a readability analysis of QR code of variable contents, size and data error correction level, which are read by smartphones running an Android platform. The experiments were performed with various types of base material on which the code was printed. Furthermore, QR code readability analysis was conducted in the case when there is a geometric deformation of the code. Based on the detailed analysis of the collected data, it can be concluded that QR code readability is not directly influenced by the number of coded characters, or by the error correction level, but only by the size of modules that constitute the code. Furthermore, the results show that the change of the base material does not influence the read time, but influences the code readability. The paper further presents an example of the proposed traceability system, where the QR codes are used for data tracking and tracing for fruit yogurts, based on the recommendations gained through the readability analysis. This traceability system concept is universal and can be used for various products with slight modifications.
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## 1. Introduction

Food product traceability is a topic that draws attention of an increasing number of researchers in the world. In order to set a traceability system, it is necessary to provide updated data that is significant to the user, such as the product origin, processing mode, storing conditions, and expiration date. In each system there is a critical point where the systematic information loss occurs when the information about a product or process is not linked to a product and recorded systematically (Hu et al., 2013), thus it is important to set the system so that the potential critical points are recognized and the problems eliminated before the implementation of the traceability system.

The appearance of the avian and swine influenza, bovine spongiform encephalopathy ("the mad cow disease") as well as frequent occurrence of undesirable substances (pesticides, heavy metals, etc.) in food products increases the need for an efficient system for tracing the origin and the processing conditions of food during production, transport and warehousing. Product traceability is an efficient way for increasing food safety and quality and to reduce the expenses for withdrawal of problematic products from the market (Regattieri et al., 2007), as well as to improve production strategies in a company (Saltini and Akkerman, 2012) and production control (Saltini et al., 2013). Product traceability is extremely important for perishable products industry (Lavelli, 2013). The European Union countries, this area is regulated with European standards for traceability and Best Available Technology (BAT), as laid down in ENISO 2205:2007 standards and the European Directive 2008/1/EC (Standardization, 2007). On the other hand, it is shown that the modern way of life leads to separation of users (consumers) and producers of food products (farmers, agriculturalists) from each other (Frewer et al., 2005; Harper and Makatouni, 2002; María, 2006; Phuong, 2013; Verbeke, 2005). This separation influences the increase in consumers distrust in the food product quality, different interpretations of conditions in which the animals should be held in order to gain satisfactory

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quality of food products from a certain land property (Bosona and Gebresenbet, 2013; Vanhonacker et al., 2008). A study (Zhang et al., 2012) shows that the consumers are willing to pay a significant positive price premium for food traceability, as such a system greatly influences the consumers trust in a certain product (Chen and Huang, 2013). (Cunha et al., 2010) shows a system for vineyard identification and vine origin based on a QR code printed on the container where the vine is transported. By reading the QR code by the mobile phone and using the internet, a user can get information about the origin, weather and other conditions in the field during the growth of grapes. This project also used other technologies, like the RFID tags, determining location by GPS, measurement of temperature, humidity and air pollution. A similar concept of traceability is shown in (Ruiz-Garcia et al., 2010), where data from the field are collected through web-based systems for data processing.

There are also studies where product traceability is used in analysis of product quality at the end of product lifecycle and the products are classified based on these results (Papetti et al., 2012; Zhang et al., 2010).

(Qian et al., 2012) Describe a study with a primary goal to develop a Wheat Flour Milling Traceability System (WFMTS), incorporating 2D barcode and radio frequency identification (RFID) technology, and to validate the system in a wheat flour mill in Chinese. Tracing each individual product is based on application of QR codes, and tracing a container with several products is based on application of RFID tags. The system described by this study is successfully implemented in a real world application.

Application of 2D codes is also present at farms, and thus (Fröschle et al., 2009) presents results that indicate applicability of Data Matrix codes for product traceability for each individual animal at poultry farms. The codes are printed on the beak and feet of the animal, and the reading of codes is performed by optical devices. It was shown that the codes printed on the beak have better read rates than those printed on the feet. Another similar research (Mc Inerney et al., 2011a, 2011b) analyzed the influence of renewing the surface of the chicken beak during the traceability period to the readability of linear and 2D barcodes that were printed on the beak. It was shown that regardless of the renewing of the beak cells, the codes are mostly readable. Potential two-dimensional codes for application in automated manufacturing, such as the food production, is presented in the paper (Osman and Furness, 2000).

Our research is aiming to develop a universal system for food products traceability, which could be applied in all or most of the food industry types. The main idea is to transfer the important information in the QR code format on the product or product packaging to the subsequent user in the food chain, which can be easily read by a 2D barcode reader or a smartphone, and the information can be gained immediately on-the-spot (Chen et al., 2013). In order to base such a system on QR codes, it is essential to ensure fast and easy decoding as well as ruggedness of the codes (Liang et al., 2013). The research presented in this paper was conducted in order to get a clear image of possibilities of packaging material application for printing the QR codes for transferring information about the product. On the other hand, it is important to determine the read speed and success rate for various sizes of QR codes, in order to select the most reliable solution. Also, the influence of the error correction levels on the QR code readability was analyzed, which provides data recovery in the case of code damage, but additionally increases the density of modules in the code.

The remainder of the paper is organized as follows. Section 2 presents the objectives of the research. It also describes the draft of the model for the product traceability system by using key data about the product, and shows the basic information about the structure of QR codes, as well as the software tool for working with QR codes. Section 3 describes the two phases of the conducted experiments. Section 4 presents the obtained results. Section 5 shows an example system for fruit yogurt production, where the traceability system is set based on the data contained in the QR code. The final section discusses the results and gives the conclusions to the paper.

## 2. Objectives

A universal system model is needed for traceability of key data for each food product. This system model should be applicable for various food production processes regardless of the specific applied technology for food processing. The traceability system should be based on technologies for automatic identification, such as RFID technology and 2D barcodes for carrying data. The research objective of this paper is determining the possibilities of QR code application for traceability of key data for each food product, by analysis of QR code readability with regards to different code content, size and error correction level, as well as different base materials for printing the code, and geometrical deformations of the code.

### 2.1. Food traceability system

RFID technology has many advantages for implementation in automated identification and traceability systems, such as the amount of data that can be contained in a tag, high reading speed of data, possibility of simultaneous reading of multiple tags, and possibility of non-contact reading of data. One of the major disadvantages of RFID technology is the price of its implementation and of single tags. This disadvantage affects the use of RFID technology in food product traceability systems, as the price of an RFID tag would greatly affect the price of a single food product. On the other hand, two-dimensional codes can store less but still a significant amount of data, and are not costly like RFID tags. They have other disadvantages, including the need for proximity of readers while reading labels, as well as the influence of the packaging condition to the code readability, which will be further detailed later in the paper (Šenk et al., 2013).

One of the most often used two-dimensional codes is QR code (Tarjan et al., 2011), which can store a sufficient amount of data, has very good readability even on small sized labels, and which also has very good readability in case of physical damage of a part of the code. The framework for a traceability system is proposed that uses both the RFID and QR codes for food product traceability, in which both the RFID and QR codes contain information about a particular product, which is therefore immediately readable with the use of an adequate reader.

The traceability system framework includes all the possible stages in a food chain, where the potential participants are: primary producers, processing industries, transport, retail and the end-consumer (Fig. 1). Each participant in the chain represents a specific stage in the transformation of food (Šenk et al., 2013).

Product tracking starts with the raw products takeover from the primary producers: farmers, agriculturalists, etc. For each entity a unique ID is generated, which enables further tracking and later tracing of the products history. In the database, further data are assigned to the unique ID, such as origin, quality and other significant information for the particular product. In each subsequent stage, significant data are generated for each entity (product or product group) and a QR code is generated with key data that is significant for the subsequent user of the specified product. RFID tags are used for group packaging, for example in transport. The user can be an operator in any stage of the production chain or the end consumer. The QR code contains the key data about the

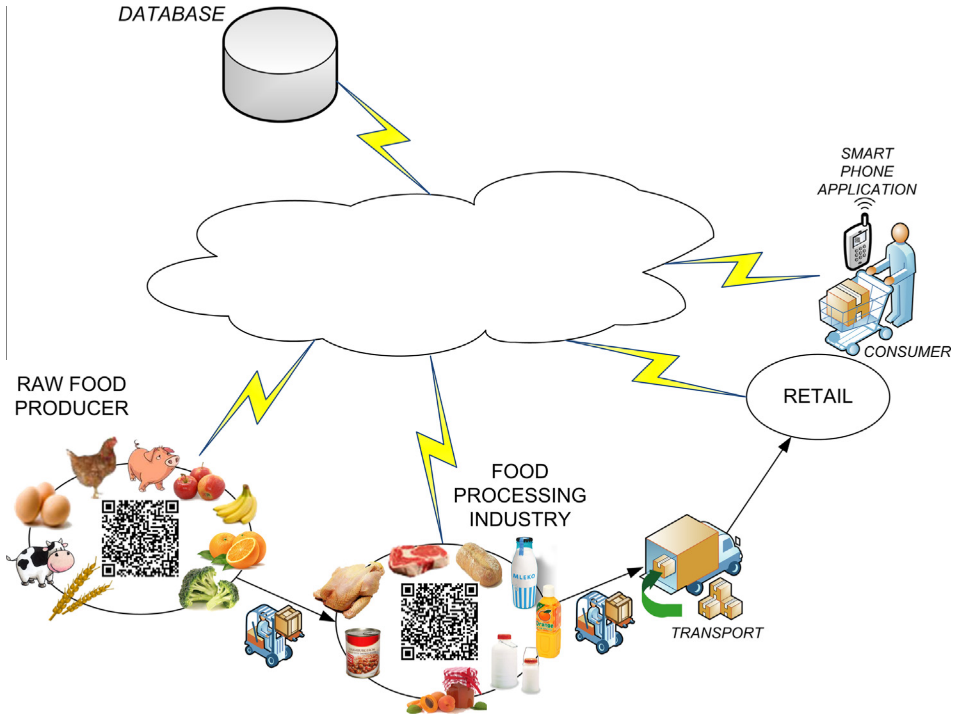


**Fig. 1.** The concept for food product traceability system.

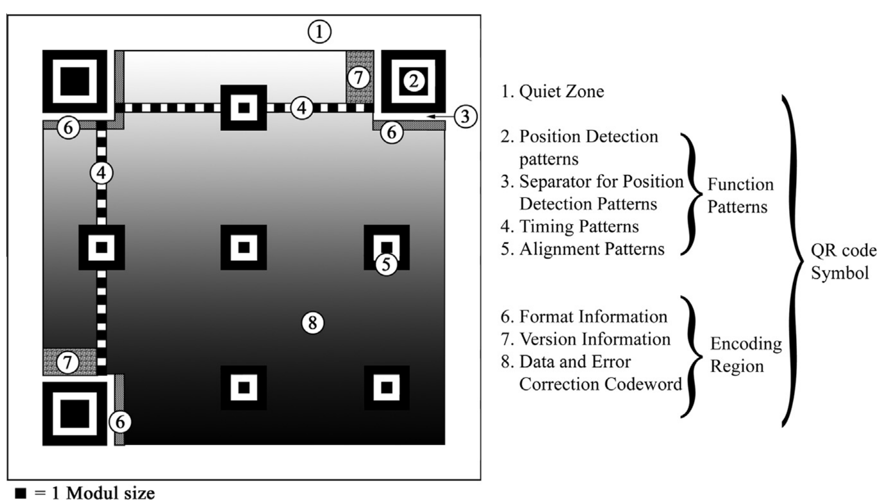


**Fig. 2.** QR code structure.

product as well as the ID, by which it is possible to find additional data from the database if needed, which the producers provided for each product, but are not printed in the QR code. If the processing of the food product includes various ingredients, the unique ID of the new product is also connected to the ID of all the ingredients, which enables later traceability of products. This way, there is a database which contains all the data on the product, from its origin, and origins of all of its ingredients, through all processing stages and transport.

### 2.2. QR code structure and the software tool for processing QR codes

QR code is a two-dimensional barcode defined by the industrial standard ISO/IEC18004:2006 (Standardization, 2006), developed and protected by the Japanese company *Denso Wave Incorporated*, which is a member of Toyota group.

QR code structure is shown in Fig. 2 (Standardization, 2006). Each QR code is structured by dark (logical "1") and light (logical "0") modules. The modules are evenly distributed in a square net of fields, where the size of a field is the size of a single module. By the standard ISO/IEC18004 one module should be sized $4 \times 4$ px (pixels) with the print resolution of 300 dpi (dots per inch). This size ensures readability by the majority of optical devices. The research results in Section 4 show that the module size of $3 \times 3$ satisfies the readability conditions, if a higher resolution camera is used. Each QR code symbol consists of Function Patterns and Encoding Regions. Function patterns do not contain the encoded data.

In the development of a food product traceability system for processing QR codes, the *ZXing* software library was used (ZXing, 2013a). ZXing (pronounced "zebra crossing") is an open-source, multi-format 1D/2D barcode image processing library imple-

**Table 1**
Used QR codes.

| No. | QR code ID | No. of characters | Error correction | QR code size | Module size (px) |
|---|---|---|---|---|---|
| 1 | 100.L.Lar | 100 | L | Large | 7 × 7 |
| 2 | 100.L.Med | 100 | L | Medium | 5 × 5 |
| 3 | 100.L.Sma | 100 | L | Small | 2 × 2 |
| 4 | 100.M.Lar | 100 | M | Large | 7 × 7 |
| 5 | 100.M.Med | 100 | M | Medium | 4 × 4 |
| 6 | 100.M.Sma | 100 | M | Small | 2 × 2 |
| 7 | 100.Q.Lar | 100 | Q | Large | 6 × 6 |
| 8 | 100.Q.Med | 100 | Q | Medium | 4 × 4 |
| 9 | 100.Q.Sma | 100 | Q | Small | 2 × 2 |
| 10 | 100.H.Lar | 100 | H | Large | 5 × 5 |
| 11 | 100.H.Med | 100 | H | Medium | 3 × 3 |
| 12 | 100.H.Sma | 100 | H | Small | 1 × 1 |
| 13 | 200.L.Lar | 200 | L | Large | 5 × 5 |
| 14 | 200.L.Med | 200 | L | Medium | 3 × 3 |
| 15 | 200.L.Sma | 200 | L | Small | 1 × 1 |
| 16 | 200.M.Lar | 200 | M | Large | 5 × 5 |
| 17 | 200.M.Med | 200 | M | Medium | 3 × 3 |
| 18 | 200.M.Sma | 200 | M | Small | 1 × 1 |
| 19 | 200.Q.Lar | 200 | Q | Large | 4 × 4 |
| 20 | 200.Q.Med | 200 | Q | Medium | 3 × 3 |
| 21 | 200.Q.Sma | 200 | Q | Small | 1 × 1 |
| 22 | 200.H.Lar | 200 | H | Large | 4 × 4 |
| 23 | 200.H.Med | 200 | H | Medium | 2 × 2 |
| 24 | 200.H.Sma | 200 | H | Small | 1 × 1 |
| 25 | 300.L.Lar | 300 | L | Large | 5 × 5 |
| 26 | 300.M.Lar | 300 | M | Large | 4 × 4 |
| 27 | 300.Q.Lar | 300 | Q | Large | 3 × 3 |
| 28 | 300.H.Lar | 300 | H | Large | 3 × 3 |
| 29 | 300.L.Med | 300 | L | Medium | 3 × 3 |
| 30 | 300.M.Med | 300 | M | Medium | 2 × 2 |
| 31 | 300.Q.Med | 300 | Q | Medium | 2 × 2 |
| 32 | 300.H.Med | 300 | H | Medium | 2 × 2 |

mented in Java, with ports to other languages. Functions for QR code generation from this library are used for generating a QR code image, which is further sent to direct printing to each product/semi product packaging. QR code can be printed directly by applying toner powder of the laser printer to the packaging material, or by using specialized lasers (for example, Marking Lasers of the producer TRUMPF) for engraving the QR codes in the packaging material.

**Table 2**
QR code sizes and error correction levels.

| Small (*Sma*) | | Medium (*Med*) | Large (*Lar*) |
|---|---|---|---|
| *Sizes of used QR codes* | | | |
| ~10 × 10 mm | | ~20 × 20 mm | ~30 × 30 mm |
| L | M | Q | H |
| *Error correction level*[a] | | | |
| 7% | 15% | 25% | 30% |

[a] Maximum percentage of data that can be recovered from a damaged code.

**Table 3**
Used smartphone models and the corresponding built-in cameras.

| Phone producer and model | Camera resolution | I phase | II phase |
|---|---|---|---|
| HTC Desire | 5 MP (2592 × 1944) | + | + |
| Samsung Nexus I9250 | 5 MP (2592 × 1936) | + | + |
| Alcatel OT990 | 5 MP (2592 × 1944) | + | + |
| Samsung Galaxy Ace S5830 | 5 MP (2592 × 1944) | + | – |
| ZTE GRAND X | 8 MP (3264 × 2448) | + | – |
| Samsung Galaxy SIII | 8 MP (3264 × 2448) | + | + |
| Samsung Galaxy Note | 8 MP (3264 × 2448) | + | + |

**Table 4**
Used paper types.

| Paper code | Paper type |
|---|---|
| 1 | Standard paper for laser printer 80 g/m$^2$ |
| 2 | Muflon with metalised shiny silver background 80 g/m$^2$ |
| 3 | Natron paper 60 g/m$^2$ |
| 4 | Niklaselect 90 g/m$^2$ |
| 5 | Woodfree offset 60 g/m$^2$ |
| 6 | Kunsdruck 115 g/m$^2$ |
| 7 | Kunsdruck 130 g/m$^2$ |
| 8 | Kunsdruck 300 g/m$^2$ |

For detection and reading of QR codes it is also possible to use dedicated functions from the ZXing library. The model for readability testing of QR codes is set so that the codes are read by smartphones with a general application for barcode reading, where the

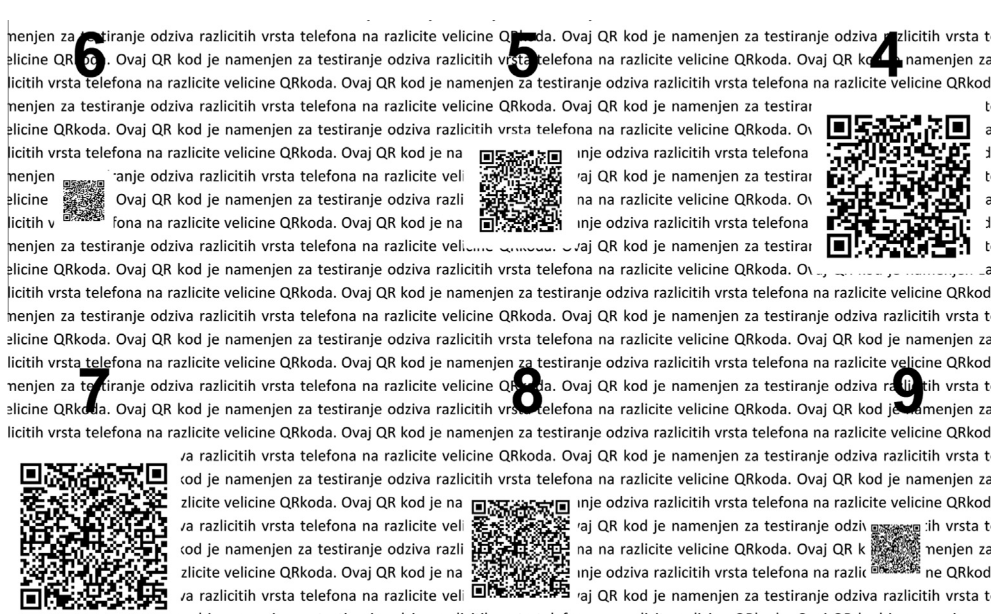


**Fig. 3.** Test paper sample.

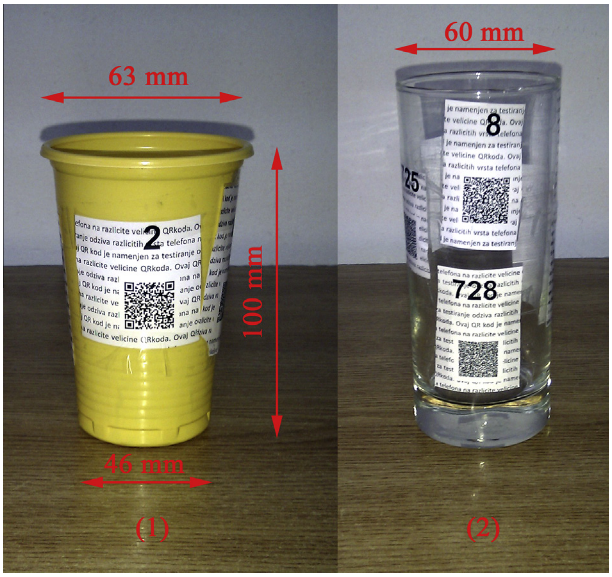


**Fig. 4.** Curved packaging samples.

function parameters are set to read multi-code format, like in most commercial reading applications, so that it can be used for detection of all the types of barcodes. Multi-code format reading leads to a little slower reading rate of the mobile device, but it was chosen because then there is no need for installing a dedicated application for this purpose, but the users can use a general application for reading barcodes on their smartphones.

## 3. Material and methods

QR code readability measurements for various types of packaging materials should provide insight to kinds of codes that are readable on certain types of packaging. These data will later be used for choosing the size and density of codes for final application on the product packaging. QR code readability analysis was conducted in two phases, on paper types that are often used as packaging material.

In the proposed food traceability system, QR codes should be used for tracking and tracing food products in the major part of food chain in processing, distribution and retail, since the costs of using the QR codes are low and they do not incur additional value to the price of a single product. Using QR codes on the food product packaging for transferring key product data should provide minimal readability conditions, which would allow the consumer to easily reach the data contained in the code. The first phase of this research is oriented to determining the format and error correction level of QR codes that would be used, as well as the length of the text contained in the code, and the second phase is oriented to comparing QR code readability on various types of paper, as well as examining the influence of geometrical deformations of QR codes to its readability. The user (a person who is trying to read the QR code) expects fast response when reading the code contents, so this is one of the most important parameters. This is essential, as the whole system model has no significance if the reading of a QR code adds delay time to existing processes that are performed on the product.

The first phase of QR code readability analysis included measurements on 32 different QR codes (Table 1) which are differentiated by code dimensions, contents and error correction level, and for this research they are printed in the middle of text on a page (Fig. 3). Codes with 100, 200 and 300 characters are generated in 3 different sizes (*Small* (*Sma*), *Medium* (*Med*), *Large* (*Lar*); Table 2), with 4 different error correction levels (L, M, Q, H; Table 2) which are defined according to standard ISO/IEC18004:2006 (Standardization, 2006). *Small* sized codes with 300 characters were not generated, as this size of codes cannot encode this amount of data. Used QR code sizes and error correction levels are given in Table 2. A testing sample is shown in Fig. 3. QR codes are inserted into text, in order to set the conditions similar to real world applications on food packaging. In the first phase of measurements, the QR codes were printed on regular paper for laser printers (Table 4, type 1).

In order to get a clearer image of readability of QR codes of various sizes by mobile phones, smartphones of various producers running the Android operating system, with different cameras, were used. Table 3 (phase I) shows the models of phones used in the first phase of research, and the resolution of their built-in cameras. All the phones are using the application *Barcode Scanner* by the *ZXing Team* that is free for download from *Google Play*®  (ZXing, 2013b). The application is using the abovementioned *ZXing* public library for application development (Android and Java) for encoding and decoding linear and 2D barcodes.

For the comparison of the results, the time for starting the application for reading QR codes, focusing the camera on the QR code, locating it and decoding its contents is measured. The measurements were performed 30 times for each code, and the final result shows the average measurement. Each type of the mobile phone was trialed for reading each of the 32 test QR codes. All measurements were performed from the same distance (15 cm) and with controlled light conditions (the camera LED was turned on).

The objective of the second research phase was to determine the influence of base material (type of paper) to which the QR code was printed, as well as the influence of the geometrical deformation of the QR code on the packaging, on the code readability. The measurements were conducted for QR code sizes that were readable in the first phase of research in a large number of read attempts. In this phase, 23 codes were used out of 32 (Table 1) codes generated in the first phase. The set of 23 codes contains 19 codes that were 100% readable in the previous phase, one code that was not readable only by one particular phone, and three codes with 300 characters Medium sized (module size $2 \times 2$) that were of special interest as this format was suggested for application in the system for food product traceability. The QR codes were printed on eight different types of paper. A list of used paper types is given in Table 4. Beside the standard white A4 printing paper, the *Muflon* paper type was used with one metalized side with a *shiny silver background* (type 2), which is mostly used for printing labels for bottles, as well as for stickers. Further, thin *Natronpaper* (type 3) is used, which is mostly used for packaging of bakery prod-

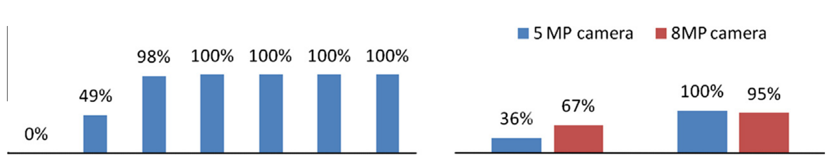


**Fig. 5.** QR code decoding success rate for various module sizes.

**Table 5**
QR code readability as a function of contents and error correction level.

| Code ID | 100.L.Med | 100.M.Med | 100.Q.Med | 100.H.Med | 200.L.Med | 200.M.Med | 200.Q.Med | 200.H.Med | 300.L.Med | 300.M.Med | 300.Q.Med | 300.H.Med |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Module size (px) | 5 × 5 | 4 × 4 | 4 × 4 | 3 × 3 | 3 × 3 | 3 × 3 | 3 × 3 | 2 × 2 | 3 × 3 | 2 × 2 | 2 × 2 | 2 × 2 |
| Average reading time (s) | 4.3 | 4.5 | 4.4 | 5.3 | 5.6 | 5.1 | 5.3 | 6.1 | 5.8 | 8.9 | 7.0 | 9.7 |
| Readability (%) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 57 | 100 | 43 | 57 | 57 |

| Code ID | 100.L.Lar | 100.M.Lar | 100.Q.Lar | 100.H.Lar | 200.L.Lar | 200.M.Lar | 200.Q.Lar | 200.H.Lar | 300.L.Lar | 300.M.Lar | 300.Q.Lar | 300.H.Lar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Module size (px) | 7 × 7 | 7 × 7 | 6 × 6 | 5 × 5 | 5 × 5 | 5 × 5 | 4 × 4 | 4 × 4 | 5 × 5 | 4 × 4 | 3 × 3 | 3 × 3 |
| Average reading time (s) | 4.4 | 4.1 | 4.3 | 4.2 | 4.4 | 4.7 | 4.5 | 4.7 | 4.7 | 4.7 | 5.0 | 5.6 |
| Readability (%) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 86[a] | 100 |

[a] QR code is unreadable only by the ZTE GRAND X.

ucts. The measurements were also performed on paper types: *Niklaselect*, *Woodfree offset* and *Kunsdruck*, which are used for making printed packaging. These papers provide good print quality and are used based on the client's requests.

Since the research in the second phase was performed after the first phase, several phone models from the first phase were no longer available for testing, so other models were chosen as a replacement. The list of used phone models and the corresponding built-in cameras is given in Table 3 (phase II).

Analogous to the first phase, in this phase, the time for starting the application for reading QR codes, focusing the camera on the QR code, locating it and decoding its contents was also measured. The measurements were again performed 30 times for each code, and the final result shows the average measurement. All measurements were performed from the same distance (15 cm) and with controlled light conditions (the camera LED was turned on). Each type of the mobile phone was trialed for reading each of the 23 test QR codes. If the phone was unable to read the code contents within 10 s, the reading was considered a fail, and the QR code unreadable. For unreadable codes, the read times were not recorded, so the average read times are given for readable codes only.

After these time measurements, the readability testing was performed for QR codes applied to objects with curves. The samples are shown in Fig. 4. The used objects were glass cylinder-shaped glasses with constant radius (2) and plastic cone-shaped glasses (1). For the cone-shaped glasses, the angle of the cone to the vertical axis is 4.86°.

## 4. Results

QR code readability testing was conducted in two phases. In the first phase, QR code readability on standard laser printer white A4 paper was tested, while the second phase included measurements for other types of paper. The second phase also tested the influence of geometrical deformations on QR code readability.

### *4.1. Results of the first phase of research*

After the performed measurements in the first phase of research, average read times are gained for each of the 32 different QR codes (Table 1) for each of the 7 phone models. Based on these data, the following characteristics can be determined:

#### *4.1.1. QR code readability as a function of base module size*

Fig. 5 shows the results of decoding performance for QR codes of different contents, with different module size. During the data processing, the measured read times are grouped by the single module size, and Fig. 5 (left) shows the percentage of reading success rate, which shows whether the QR code is readable or not. The abscise represents module sizes (1 × 1 px, 2 × 2 px, 3 × 3 px, 4 × 4 px, 5 × 5 px, 6 × 6 px and 7 × 7 px), and the ordinate the success rate in reading all the QR codes with the given module size in percentage (%). The graph shows that despite of the high resolution of the built-in cameras in the used phones (5 and 8 megapixels) the QR codes with module size of 1 × 1 px are not readable. These codes are unreadable due to the fact that with printing resolution of 300 dpi (dot per inches) the size of a 1 × 1 px module is around 90 μm, which leads to distortion of the corners when printing to the paper. The other limiting factor is the fact that the camera cannot focus to such small details, and the detection of so small codes is practically impossible. The QR codes with module size of 2 × 2 px give slightly better results, and the readability for this size of codes is 49%. Good readability was achieved with QR codes with module size of 3 × 3 px, while all the codes with bigger modules were read in all cases (100%). Fig. 5 (right) shows the measurement

**Table 6**
QR code readability on different paper types.

| Module size (px) | Paper types (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 2 × 2 | 52 | 0 | 7 | 0 | 13 | 7 | 7 | 0 |
| 3 × 3 | 98 | 77 | 77 | 86 | 83 | 89 | 89 | 86 |
| 4 × 4 | 100 | 100 | 96 | 92 | 100 | 100 | 96 | 100 |
| 5 × 5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 6 × 6 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 7 × 7 | 100 | 80 | 100 | 100 | 100 | 100 | 100 | 100 |

results for modules sized 2 × 2 and 3 × 3 px, for cameras with 5 and 8 megapixels (MP) separately. This figure shows that the higher resolution cameras give better readability results. QR codes with modules sized 3 × 3 px and bigger give satisfactory results. Only the Samsung Galaxy Note phone model showed problems in reading QR codes with 3 × 3 px modules.

#### 4.1.2. QR code readability as a function of the amount of encoded data and error correction level

Table 5 shows the measurement results (QR code readability and read times) as a function of number of characters encoded, of the error correction level and the size of the QR code (Table 2). Small sized QR codes were left out, as these codes are unreadable, which is shown in Fig. 5. Codes with 100 and 200 characters encoded are readable with acceptable read times of few seconds (<10 s) irrespective to size (Medium or Large) and the error correction level. Medium sized QR codes with 300 characters lead to difficulties in reading, especially with phones with 5 MP cameras, as the higher number of characters and the requested Medium format lead to decrease in module sizes to 2 × 2 px. On the other hand, the phones that were able to read the code had read times similar to other larger codes. For Large sized codes, there was no problem in reading the contents, even when 300 characters were encoded, except for one phone model ZTE GRAND X, which had problems in decoding a QR code with 300 characters and error correction level Q. With this phone model, the code was read after a longer time interval (>20 s), and thus is regarded as unreadable for this phone model.

### 4.2. Results of the second phase of research

In the second phase of research, read rate measurements were repeated for QR codes that were readable in the first phase. Beside these codes, three codes with modules sized 2 × 2 px were included, in order to test whether the codes are readable on another base material. In this phase, the codes were printed on different paper types, which are shown in Table 4. The attained readability results, grouped by the size of modules in a QR code, are shown in Table 6.

The results show that QR codes with module size 2 × 2 px are also unreadable on the paper types used in the second phase. From 52% readability for standard white paper (type 1), the readability decreases to around 10% with other paper types, and in certain cases the codes are completely unreadable. For modules sized 3 × 3 px the situation is different, there is a noticeable decrease in readability for shiny paper types, such as Muflon and Natron paper, but the readability is good for harder paper types like Kunsdruck. The codes with modules sized 4 × 4 px and larger show good readability. The paper with shiny surface arise difficulties in reading, mostly with codes with bigger dimensions (Medium and Large code size). Table 7 shows the readability for codes with modules sized 4 × 4 and 7 × 7 px, where it is clearly shown which

**Table 7**
QR code readability for various error correction levels.

| Error correction | Code size | Module size (px) | Paper types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| M | Medium | 4 × 4 | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| Q | Medium | 4 × 4 | 100% | 100% | 100% | 80% | 100% | 100% | 100% | 100% |
| Q | Large | 4 × 4 | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| H | Large | 4 × 4 | 100% | 100% | 80% | 80% | 100% | 100% | 80% | 100% |
| M | Large | 4 × 4 | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| L | Large | 7 × 7 | 100% | 60% | 100% | 100% | 100% | 100% | 100% | 100% |
| M | Large | 7 × 7 | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

**Table 8**
Read times for decoding the QR codes from various paper types.

| Code ID | Module size (px) | Paper types 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Camera resolution (mega pixels) | | | | | | | | | | | | | | | |
| | | 5 | 8 | 5 | 8 | 5 | 8 | 5 | 8 | 5 | 8 | 5 | 8 | 5 | 8 | 5 | 8 |
| 100.L.Lar | 7 × 7 | 4.7 | 4.3 | 5.3 | 4.2 | 4.7 | 3.7 | 4.6 | 3.7 | 4.8 | 3.7 | 4.6 | 3.7 | 4.8 | 3.6 | 4.8 | 3.7 |
| 100.L.Med | 5 × 5 | 4.7 | 4.0 | 6.0 | 3.6 | 5.9 | 3.7 | 5.0 | 3.6 | 4.6 | 3.6 | 5.3 | 3.6 | 5.0 | 3.7 | 5.3 | 3.7 |
| 100.M.Lar | 7 × 7 | 4.4 | 3.8 | 4.9 | 3.6 | 4.6 | 3.6 | 4.6 | 3.6 | 4.8 | 3.7 | 4.5 | 3.6 | 4.9 | 3.6 | 4.9 | 3.8 |
| 100.M.Med | 4 × 4 | 4.8 | 4.2 | 5.8 | 3.5 | 6.5 | 3.6 | 5.4 | 3.6 | 5.7 | 3.6 | 5.5 | 3.6 | 5.5 | 3.6 | 5.8 | 3.6 |
| 100.Q.Lar | 6 × 6 | 4.4 | 4.3 | 4.9 | 3.8 | 4.9 | 3.8 | 4.6 | 3.7 | 4.4 | 3.7 | 4.6 | 3.8 | 4.8 | 3.6 | 4.4 | 3.7 |
| 100.Q.Med | 4 × 4 | 4.4 | 4.5 | 6.9 | 3.8 | 7.8 | 3.8 | 5.3 | 3.7 | 6.2 | 3.8 | 6.3 | 3.7 | 6.1 | 3.7 | 6.9 | 4.1 |
| 100.H.Lar | 5 × 5 | 4.5 | 3.8 | 5.8 | 3.5 | 5.6 | 3.6 | 4.8 | 3.6 | 5.2 | 3.7 | 5.2 | 3.8 | 4.7 | 3.7 | 4.7 | 3.7 |
| 200.L.Lar | 5 × 5 | 4.4 | 4.4 | 5.2 | 3.5 | 4.9 | 3.9 | 4.6 | 3.6 | 5.0 | 3.6 | 4.7 | 3.7 | 4.7 | 3.8 | 4.8 | 3.6 |
| 200.M.Lar | 5 × 5 | 5.4 | 3.8 | 4.9 | 6.2 | 5.4 | 4.0 | 4.6 | 3.9 | 4.8 | 3.8 | 4.7 | 3.7 | 4.7 | 3.7 | 5.1 | 3.7 |
| 200.Q.Lar | 4 × 4 | 4.7 | 4.4 | 6.6 | 3.7 | 5.6 | 3.8 | 5.4 | 3.6 | 5.2 | 3.7 | 5.7 | 3.6 | 5.5 | 4.0 | 7.3 | 3.6 |
| 200.H.Lar | 4 × 4 | 4.8 | 4.6 | 9.4 | 3.6 | 5.5 | 4.8 | 5.8 | 3.9 | 7.5 | 4.0 | 11.3 | 3.8 | 4.7 | 3.7 | 7.0 | 4.0 |
| 300.L.Lar | 5 × 5 | 4.9 | 4.4 | 6.3 | 3.7 | 5.7 | 3.7 | 5.3 | 3.7 | 6.0 | 3.8 | 5.5 | 3.6 | 5.3 | 3.8 | 5.1 | 3.7 |
| 300.M.Lar | 4 × 4 | 4.8 | 4.7 | 7.0 | 3.9 | 5.7 | 4.3 | 5.5 | 4.2 | 6.2 | 3.9 | 6.3 | 3.9 | 5.7 | 3.8 | 6.4 | 3.8 |

**Table 9**
Readability for intentionally deformed QR codes.

| Glass type | Code ID | Module size (px) | Readability | Average response time (s) |
|---|---|---|---|---|
| (1) | 100.L.Lar | 5 × 5 | 66% | 6.1 |
| (2) | 100.L.Lar | 7 × 7 | 83% | 5.9 |
| | 100.L.Med | 5 × 5 | | 4.9 |
| | 100.M.Med | 4 × 4 | | 5.1 |

papers induce difficulties in reading. In these cases, the codes were unreadable due to the inability of specific phone models to focus on the given code size from the given position. From the technical aspect, this is not a limitation, as the readability can be improved by correcting the auto focus algorithm (Zamberletti et al., 2011).

Based on the results presented in Table 7 it can be concluded that for printing the QR codes, the paper types 1, 5, 6 and 8 can be used for all presented QR code variants with sizes 4 × 4 px and 7 × 7 px.

Table 8 shows the average read times for decoding the contents of QR codes. The read times are given for all the paper types used in the research (Table 4). The average read times were calculated only from the data for the phone models that could read the given QR code. The data is shown separately for the phones with 5 MP and 8 MP cameras. The read times for QR codes with modules smaller than 4 × 4 px are not shown, as these codes do not meet the criteria that they are readable by most users, which is already shown in the previous part of the paper. By the analysis of the data, it can be concluded that the read times for QR codes are not influenced by the paper type, but rather the hardware of the phone model that performs the decoding of the data from the image of the code. This leads to the conclusion that the read times are influenced by the camera resolution and the phone speed, which are higher for new phones in contrast to older phones that have lower processing speeds and camera resolutions.

After the testing of QR code readability on various paper types, the readability of QR codes was tested on objects with curves (Fig. 4). These measurements were conducted in order to test the influence of geometrical deformations to the code readability. QR codes were intentionally deformed by attachment to the glasses. The plastic cone-shaped glasses (1) and glass cylinder-shaped glasses (2) were used (Fig. 4). Out of the 23 codes with code deformations in two axis (by attachment to the cone-shaped glass), only one code was readable, and only in 66% of situations. Slightly better situation is for codes with deformation in one axis, since in this case 3 code sizes were readable, with noticeably higher read rate. Table 9 shows the times and read success rates for the codes that were readable.

The acquired results in the last part of research are not encouraging, as in real world applications flexible packaging is often used (paper and nylon bags) as well as cylinder-shaped packaging boxes, where there is a high probability that the codes will be deformed. For the flexible packaging this is not a big problem, as the user can intuitively straighten the code when grasping the product, but for attaching the code to curved hard surfaces this is not possible. In this case there are two possibilities, to add an algorithm for correction of distortion to the image processing in the mobile phone, or to print the codes in a distorted manner, so that when the image of the code is taken the code shows in the right format. The first possibility requires higher processing power of the phone, as there is additional image processing, but the other possibility limits the distance from which the code is readable and is not a universal principle as the curvature can change in many packaging due to its flexible structure.

## 5. An example of a traceability system for fruit yogurts

In this chapter, an example of a traceability system is presented, that tracks important data for each individual product, or a batch of products with same characteristics. These data can influence the consumer's decision to buy the end product, as they get the opportunity to choose a specific product (e.g. from a specific geographic area). The system example shows the application of QR code in the product traceability system through stages of product's life cycle and on the end product packaging. The example illustrates a traceability concept for data tracking and tracing for fruit yogurts, although the proposed traceability concept is universal and applicable to various types of food products with slight modifications. QR codes with module size 4 × 4 px and error correction H are used, printed on self-adhesive paper type 1, which were proved adequate for this application based on the performed analysis.

Since the yogurt production is a closed process that is conducted under controlled conditions, two key points were chosen where the ingredients and process data are entered into the database, while the data are connected to a unique ID code for each unit. This database is located on a local server. The data chosen for presenting in the QR code are taken from the database. QR code is attached to the product or semi-product at the two key points, thus the chosen data are readable without the need to access the database. The data that should be publicly available are copied to another database, which is later accessible via internet by scanning the ID code from the product's QR code by a dedicated smart phone application, if the consumer wants to find more data about the product than the data presented in the QR code. The main reason for copying the data is that the publicly available database is intended to be universal for various products that use this traceability concept, for multiple producers. Another reason is that the local database is internal for the company, and contains lots of data that are not related to product tracking and tracing, and only the data that are related to product tracking and tracing are copied to the publicly available database. Furthermore, some companies do not allow connecting their internal databases to the internet for security reasons.

At the key point I, milk is delivered in tankers by the individual farmers or their representatives, milk quality is determined, and the data are entered into the database. When receiving milk from the farmers, the following data are entered into the database:

- Product description (milk and cattle breed).
- Farm designation, location/area.
- GPS coordinates of the farm.
- Date and time of milking.
- Date and time of delivery.
- Quantity.
- Quality.
- Remarks.
- Operator that received the milk.

After the required data are entered into the database, the chosen data that are needed for further milk processing are printed in the form of QR code, and manually attached to individual milk canisters or tanks. The chosen data include: ID code, date and time of delivery, quantity and operator. Fig. 6 shows an example of a label with the printed QR code in this stage (the presented data are not actual data, they only illustrate the data structure within the code).

Further on, the milk is transferred into tanks for starter cultures where yogurt production process starts. Before the transferring, the milk for the process is identified by reading the QR code on the tank, and the identified ID code is connected to the ID code

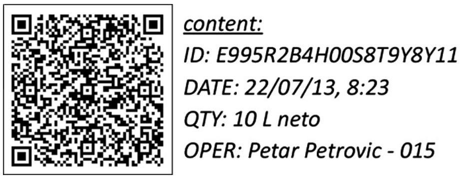


**Fig. 6.** Label for the tank.

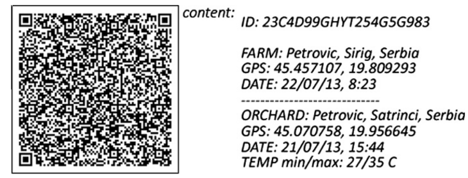


**Fig. 8.** Label for the final product.

of the process batch, which later serves as the connection for the final products. Production process for fruit yogurts starts together with all other yogurts, and is only separated in a later point, which is chosen as the second key point, where fruit is added to the yogurt, and further fermentation, cooling and packaging of the yogurt takes place. Afterwards, the QR code with the key data for the final products is generated and attached to the products.

The fruit intended for fruit yogurt production is delivered to the factory as fresh or frozen fruit, depending on the season. The fruit is transported in smart returnable plastic packaging that contains an RFID tag (Fig. 7. shows the plastic packaging with grapes, but it can be used for various types of fruit). In the memory of the RFID tag, the data about the fruit origin and the conditions during transport are written.

The data about the fruit origin contain: GPS coordinates of the orchard or vineyard where the fruit was picked, the date and time of picking, weather conditions (min/max temperature during the day), where these data are automatically written in the RFID tag in the plastic packaging during the picking, via RFID readers implemented in the fruit transporters. The plastic packaging is intended for multiple uses, so the data from the RFID tag are erased when the fruit is delivered.

In the factory, when receiving the fruit, the data from the RFID tag are automatically read and written to the database, while the data about the fruit quality class are determined by the operator, and a unique ID code for each group unit is connected to the existing data. A group unit is defined for a fruit quantity of the same quality class from the same orchard/vineyard. For each ID code, the following data are connected:

- Product description (fruit type).
- Orchard/vineyard designation, location/area.
- GPS coordinates of the orchard/vineyard.
- Date and time of fruit picking.
- Maximum and minimum temperature during the day of picking.
- Date and time of delivery.
- Quantity.
- Quality.
- Remarks.
- Operator that received the fruit.

**Fig. 7.** Plastic packaging for fruit or vegetables with an embedded RFID tag (LabbGroup (2013)).

After the bottling of the finished yogurt in 1 L and 0.5 L packaging, a label with a QR code (Fig. 8 shows an example label for the final product, the encoded data are not actual data, they only illustrate the data structure within the code) is printed on self-adhesive paper type 1, and attached to each bottle in the part which has the slightest curvature in order to avoid geometrical deformations (Fig. 9). This QR code gives information about the origin of raw ingredients of the product to the consumer, and thus facilitates the decision process for buying a particular product, which is no longer connected only to the specific brand, but also to particular suppliers of raw ingredients. The consumer can read the following data contained in the QR code on the product via a smartphone:

- ID code of the product (which can be used to get further available data from the database via internet, when using a dedicated smart phone application).
- Farm designation, location/area of the farm where the milk originated (if the total milk quantity contains milk from various farms, only the biggest producer is provided, and the others can be identified by accessing the database).
- GPS coordinates of the farm.
- Date and time of milking.
- Orchard/vineyard designation, location/area of the orchard/vineyard where the fruit originated (if the total fruit quantity contains fruit from various orchards/vineyards, only the biggest producer is provided, and the others can be identified by accessing the database).
- GPS coordinates of the orchard/vineyard.
- Fruit quality class.

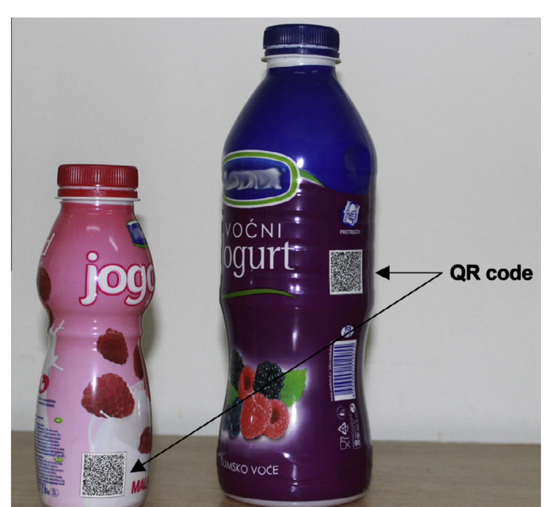


**Fig. 9.** Fruit yogurt in 0.5 L and 1 L packaging with a label with a printed QR code.

- Date and time of fruit picking.
- Maximum and minimum temperature during the day of picking.

The described system enables tracking of the product during the production, and further enables tracing of the product back to the origin of the ingredients, which can potentially save people from health problems.

## 6. Discussion and conclusions

This paper presented the results on a QR code readability analysis on various paper types for food product packaging. The sample included codes of various contents, dimensions and error correction levels. Reading of QR codes was performed with newer generation smartphones running the Android operating system. This research did not include phones with other operating systems for two reasons, the first is the presence in the market (phones with the Android operating systems are currently the most common phones in the market), and the other is the fact that phones with other operating systems cannot use the application based on *ZXing* public library for application development, which is used in the research for development of automatic generation of QR codes and reading these codes in the process of labeling, tracking and tracing of individual food products. The research also did not include phones with lower resolution of the built-in camera, as they have problems with reading 2D barcodes in general due to the low resolution of the code image.

Under the assumption that all the codes were read from the same distance and with controlled light conditions, it can be concluded that the QR code readability is not directly influenced by the number of encoded characters, or the error correction level, but only by the size of the code modules that constitute the code. The readability can indirectly be influenced by the code contents, i.e. the number of characters, only if the final dimensions of the code are predefined, as in this case the increasing of the number of characters decreases the size of the modules. The results also show that the error correction levels of QR codes do not influence the code readability, but only the possibility of data recovery from the damaged QR code.

The second part of research shows that the change of base material on which the QR code is printed does not influence the read times, but only the readability. For certain code sizes the change of the base material leads to unreadability, since some materials lead to higher reflectivity of the "light" modules, which influences the autofocus of the camera, and the acquired images are blurry and unclear, and thus unreadable. The analysis shows that the codes with the base module sized $5 \times 5$ and $6 \times 6$ px are always readable, regardless of the base material. The codes with base modules sized $4 \times 4$ px are always readable on paper types 1, 2, 5, 6 and 8, and are readable in more than 92% on other paper types. The codes with base modules sized $7 \times 7$ px are unreadable only on highly reflecting surfaces, like the metalized labels, and are 100% readable on all other paper types.

The paper also addresses the geometrical deformation of codes on the product packaging, which leads to decreased readability or even unreadability. The best readability is registered with QR codes with modules sized $5 \times 5$ px, and it was 83%. The same readability was registered with QR codes with modules sized $4 \times 4$ px and $7 \times 7$ px, but with slightly lower average response time. The paper also gives some directions for solving the problem of reading the distorted codes. These directions should be researched in further work.

This research included only undamaged QR codes, printed with a laser printer with the resolution of 600 dpi. Further work should concentrate on similar research on codes printed or engraved with other technologies, and with smaller or larger damage level, in order to get a more complete image of QR code readability.

The Section 5 presents a concept for fruit yogurts labeling based on QR code, which enables traceability of products and provides additional information about the particular product. For the presented system example, self-adhesive paper type 1 was chosen for printing the QR codes, as it is easily applicable in the existing process. According to the analysis, for this paper type the smallest fully readable module size is $4 \times 4$ px, and thus this module size was chosen in order to make the printed codes as small as possible. Error correction H was chosen as, according to the standard ISO/IEC18004, it provides the best error correction level in the case when the code is damaged.

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