Two-Dimensional Barcodes Usage in Plastic Pipes Blockchain-Based Supply-Chain

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Abstract. The use of counterfeit products causes considerable financial damage to the states and companies. Product labeling and tracking in a blockchain-enabled system can overcome this problem. One- and two-dimensional barcodes are accessible and have cheap labeling technologies, but it can be challenging to read the labels on products with curved shapes. This paper presents the plastic pipe labeling problem and its solution with two-dimensional barcodes, integrated with a blockchain-enabled supply chain. The labeling technique choice is based on QR and Aztec barcodes readability empirical study for different barcode parameters, reading software libraries for flat and curved surfaces.

1. Introduction

Different countries and communities exchange goods and services within and across the globe within the supply chain networks [1]. Over a period of time, a simple supply chain structure has evolved into a complex form and has included multiple entities on its basis. Further, the individual responsibility of manufacturing, transportation, distribution, and retailing across the platform has increased, starting from the raw material to the end product. A multilevel supply chain creates the growth of possible counterfeit goods and damage to the company’s intellectual property. Information technology has drastically changed the supply chain’s working structure, making it transparent by providing tracking and tracing options to the customer. This innovation still poses inefficiency in the supply chain transparency on the product’s entire flow, leaving loopholes for counterfeiting activities.

Blockchain technology is an underlying technology on which most modern cryptocurrencies are built upon [2, 3, 4]. Recently the scope of blockchain technology has moved beyond electronic money to different domains like healthcare, education and supply chain management [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Companies use different methods to read the information of...
the product, store on the blockchain and retrieve the data. With the potential use of blockchain technology [16, 17], supply chain companies can overcome the significant problem of counterfeited products.

Product-based manufacturing companies like plastic-pipes have faced considerable financial loss due to counterfeit products impacting states and companies. Integrating with a blockchain-based supply chain guarantees the invariability of pipes mass-production and usage. Product labeling on different surfaces should be economical without increasing the cost of the product. It can read, store, write the data directly without any human involvement. Common AIDC technology includes 1D and 2D barcodes, RFID, biometric processes like fingerprint, facial recognition system, etc. [18, 19, 20, 21, 22]. These processes are cheap and reliable hence not increasing the overall cost of the product.

This research aims to choose a generation technology for machine-readable labels for surfaces with different curvature and that fulfilling the data storage criteria. Although these labels are used to track plastic-pipes within the blockchain-based supply chain, the results can be applied for other industries. The proposed approach may be not complete and not optimal, but meets practical requirements.

2. Pipe Labels as Component of Supply-Chain
The issue of combating counterfeit products is so acute in some industries that it led to the unification of manufacturers of quality products into industrial associations that centrally take practical steps to identify and suppress the activities of organizations producing low-quality products. A striking example is the Pipe Systems Manufacturers Association (PSMA) [23] in Russia, which considers the fight against counterfeit products as one of its top priorities.

According to PSMA estimates, the share of counterfeit products in the polyethylene pipe market is 30% of the total volume, which amounts to 9 billion rubles per year (approximately 145 million USD) [24]. Recently, PSMA and Polyplastic Group—the leading producer of polymer pipes in the Commonwealth of Independent States (CIS) [25]—have started to test a scenario for using modern IT technologies to combat the situation with counterfeit products on the market [15]. One of the critical components of the struggle is labeling pipe products and the possibility of organizing product traceability until it is no longer in circulation.

The number of producers of pipe raw materials is limited in Russia: in 2018, there were two certified producers, and another producer is planned to appear in 2020. Counterfeit products are made from non-pipe or secondary raw materials. The mass of manufactured raw materials does not correspond to the mass of manufactured pipe products.

The Exonum-based [26] blockchain supply-chain management system was launched at the largest polymer pipes manufacturer in Russia—Klimovsk pipes factory, in September 2019. It ensures transparent, immutable, and cryptographically verifiable events log [17]. Each pipe has its unique identifier (UID) within the system to provide information reliability. For this purpose, the pipe is applied with a label containing UID and the associated information.

Information about changes in the pipe’s life cycle stages with a given UID has to be recorded on the blockchain to exclude data manipulation. This can be done if applied a barcode to a pipe and read by a specialized application.

The label contains the following fields: UID, batch number, name of pipes manufacturer, nomenclature name, length, diameter, the nominal outside diameter to the nominal wall thickness ratio (SDR), certificate of conformity number, type of raw-material, normative indicators of the raw material, manufacturing date, weight per meter.

The following requirements have been set for the label by pipe manufacturers:

• The label should contain the same information both in a machine- and human-readable forms.
The label should contain UID.

To read the information in a machine-readable form, an offline smartphone with pre-installed software should be enough.

The label must guarantee a capacity of 250 bytes in a machine-readable form.

The label should be read from pipes with a diameter starting from 110 mm. In the future, it should be read from any real-world pipes.

It is worth noting that the current status is not recorded on the label, as it changes during the pipe’s life cycle. Pipe statuses are recorded in the blockchain and correspond to the following actions with the pipe: produced, shipped, accepted, withdrawn from circulation (installed at the place of use).

Furthermore, there are restrictions on the pipe status changes. Namely, the pipe can not be shipped until a batch certificate is not loaded to the blockchain that corresponds to the quality control department checking passage.

Hereafter we consider only machine-readable parts of labels.

3. Label Types

The comparison of 1D, 2D barcodes, and RFID is given in Table 1. Among AIDC labels, 2D barcodes meet the requirements and support error correction, whereas 1D barcodes do not have enough data capacity, and rewritable RFIDs are expensive. Reading the code on the product concerns its content, size, printed material, error correction, and material on which it is printed. Reading depends on two main factors—first, format and error correction, and second, readability condition i.e., surroundings the environment and geomaterial deformation. Reed-Solomon code error correction [27] is capable of correcting damaged or distorted codes and is capable of error correction. The error correction depends upon the size of the code.

Table 1. AIDC labels

| Type            | Read/Write | Data Capacity (Bytes) | Built-in Error Correction | Cost per Tag       |
|-----------------|------------|-----------------------|---------------------------|--------------------|
| 1D barcode      | Read       | 100                   | No                        | No additional costs|
| Code 128        |            |                       |                           |                    |
| 2D barcode      | Read       | 3 000                 | Yes                       | No additional costs|
| QR code         | Read and Write | 10.512 000           | No                        | $0.05..$1.00       |

Several 2D barcode standards exist (see Table 2) possessing properties like offline reading, black and white, and easy availability, are suitable for research. But not all were compatible as some lacked error correction properties, square pixels, and special software(s) requirement to read (Marked in red). Out of all, only QR codes and Aztec Code fulfilled the conditions. Reading Data Matrix requires a 2D image scanner or vision system, which enterprises use not by consumers [28].

Different software and libraries can read codes: Aztec Reader is used for reading the Az codes using mobile devices; it can read in extreme conditions. BoofCV or alternative OpenCV is an open-source library for computer vision; it is a low-level image processing QR code reader. Dynamsoft code reader is a multiple barcode reader able to read multiple labels at a time and able to recognize both QR and Az codes. RNCamera (React Native Camera) is a React Native library capable of reading the barcode. RNBarcode (React Native Barcode) is an alternative library for scanning. It can use 3rd party code from AVFoundation (Apple), Vision, and ZXing.
Table 2. 2D barcodes

| Sample | Aztec | Codablock-F | Data Matrix | MaxiCode | PDF417 | QR |
|--------|-------|-------------|-------------|----------|--------|----|
| Square pixels | Yes | Rectangular | Yes | No | Rectangular | Yes |
| Data capacity | 2 Kb | 9 Kb | 3 Kb | 90 B | 1.1 Kb | 3 Kb |
| Built-in error correction | Yes | No | Yes | Yes | Yes | Yes |

4. Barcodes Readability Empirical Analysis

4.1. Experimental Setup

Readability analysis might provide insight into its ability to read the codes on a certain type of surface for a specific software library. The research conducted two different types of surfaces: flat and curved (cylinder with the diameter equals 110 millimeters, which corresponds to the minimum allowed pipe diameter). For each surface, three different types of labels were used: QR codes with 7% of error correction (qr-7), Aztec with 7% (az-7), and 33% (az-33) of error correction. For each type of label, 40 labels of different properties (size and capacity) were used: bytes capacity varied from 25 to 200 (25 bytes step) and size from 2 cm to 4 cm (0.5 cm step). We tried to recognize each label with six image recognition libraries in a bright room, keeping the reading camera (12 megapixels, with optical stabilization and phase detection-based autofocus) at a distance of 25 centimeters. The results are graded with points from 1 (worst) to 5 (best) based on the ability to read the code under factors such as the necessity of forced focusing, possibility of reading at an angle, and efforts for reading: (1) not readable, (2) readable but not reliable, (3) readable at specific angle, (4) focus required to read, (5) easily readable. Aztec readers gave a result for only Aztec codes and cannot read QR codes, whereas BootCV can read only QR codes, not Aztec.

Note 1. Angular pixel size is supposed to be a key factor for the recognition: the bigger, the better is readability for small scale. As the camera-label distance is fixed in the experiment, the angular pixel size is a monotonically increasing function of a pixel’s linear size, which is directly proportional to the linear size of the label and inverse to the bytes capacity. Az-33 has a smaller angular size compared to az-7, as it contains more redundant information to correct errors.

Note 2. The code distorts on a curved surface. For a considered cylindric case, the barcode occupied from 10 to 20 degrees of its circle.

4.2. Results

4.2.1. Flat Surface. Readability results of barcodes on a flat surface are presented in Table 3. Reading QR codes is less difficult comparing Aztec codes. In most cases, regardless of size (cm) to capacity (bytes) ratio, the reader can read the labels.

4.2.2. Curved Surface. Readability results of barcodes on curved surfaces are presented in Table 4. With an increase in size, the labels are difficult for recognition, position patterns on the label are not visible. Small labels with fewer bytes are easier for recognition.
Table 3. Readability results for flat surface

| Reader | qr-7 | as-7 | az-33 |
|--------|------|------|-------|
|        | Size (Bytes) | Size (CM) |      |      |      |      |
| Aztec Reader | 2 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 1 5 5 5 5 5 5 5 | 5 5 5 5 5 5 5 5 5 5 5 4 |
|         | 2,5 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 1 5 5 5 5 5 5 5 | 5 5 5 5 5 5 5 5 5 5 5 4 |
|         | 3 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 1 5 5 5 5 5 5 5 | 5 5 5 5 5 5 5 5 5 5 5 5 |
|         | 3,5 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 1 5 5 5 5 5 5 5 | 5 5 5 5 5 5 5 5 5 5 5 5 |
|         | 4 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 1 5 5 5 5 5 5 5 | 5 5 5 5 5 5 5 5 5 5 5 4 |
| BootCV | 2 | 5 5 5 5 5 5 5 1 1 1 1 1 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 5 5 5 5 5 5 5 4 |
|         | 2,5 | 5 5 5 5 5 5 5 1 1 1 1 1 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 5 5 5 5 5 5 5 4 |
|         | 3 | 5 5 5 5 5 5 5 1 1 1 1 1 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 5 5 5 5 5 5 5 5 |
|         | 3,5 | 5 5 5 5 5 5 5 1 1 1 1 1 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 5 5 5 5 5 5 5 5 |
|         | 4 | 5 5 5 5 5 5 5 1 1 1 1 1 | 1 1 1 1 1 1 1 1 1 1 1 1 | 5 5 5 5 5 5 5 5 5 5 5 5 |
| Dynamsoft | 2 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 4 |
|         | 2,5 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 4 |
|         | 3 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 3,5 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 4 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
| Java | 2 | 5 5 5 5 5 5 5 5 5 5 5 5 | 4 4 3 3 2 1 | 1 5 5 5 5 4 3 3 3 |
|         | 2,5 | 5 5 5 5 5 5 5 5 5 5 5 5 | 4 4 3 3 2 1 | 1 5 5 5 5 4 3 3 3 |
|         | 3 | 5 5 5 5 5 5 5 5 5 5 5 5 | 4 4 3 3 2 1 | 1 5 5 5 5 4 3 3 3 |
|         | 3,5 | 5 5 5 5 5 5 5 5 5 5 5 5 | 4 4 3 3 2 1 | 1 5 5 5 5 4 3 3 3 |
|         | 4 | 5 5 5 5 5 5 5 5 5 5 5 5 | 4 4 3 3 2 1 | 1 5 5 5 5 4 3 3 3 |
| RNBarcodes | 2 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 4 |
|         | 2,5 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 4 |
|         | 3 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 3,5 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 4 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
| RNCamera | 2 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 2,5 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 3 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 3,5 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |
|         | 4 | 5 5 5 5 4 4 4 4 4 4 4 4 | 3 3 3 3 3 3 3 3 3 3 3 3 | 5 5 5 4 3 3 3 3 3 3 3 3 |

With the increase of both size (cm) and capacity (bytes), the code’s ability to read reduces. Adding the algorithm for correction of distortion will increase the label’s cost and require the higher processing power of the phone to read the code. Also, big labels will not be readable at small diameter curved surfaces in any case because the curvature will hide the label, and the camera would not identify the pattern position.

4.3. Pipe Label Parameters Choice

For both the surfaces, we infer that small size (cm) and capacity (bytes) labels have good readability for both Aztec and QR codes, but are limited to byte storage capability. QR codes are readable with most of the software libraries, so we chose it for the project. To meet both readability and capacity requirements, one can store information in multiple smaller codes: barcodes can be divided into multiple data areas using the structure append feature [29]. Conversely, information stored in multiple barcode symbols can be reconstructed as a single data symbol. Once applied on a curved surface, each of the components is less curve and easier to scan. Applying this approach, we stopped the choice at 4 x 2 cm QR-7 codes with 75 bytes capacity (see Figure 1).

5. Conclusion

This paper presented results of QR and Aztec codes readability from a flat surface and curved surface. Different in-built libraries and programs were used for measuring readability with the help of a smartphone camera. The readability of the labels does not depend on size (cm) to capacity (bytes) ratio, but for curved surfaces, readability decreases with the size and capacity increase. Moreover, the code readability does not depend on the error correction level, which is
Table 4. Readability results for curved surface

| Reader       | qr-7 | az-7 | az-33 |
|--------------|------|------|-------|
| Size (Bytes) | 25   | 51   | 75    | 111  | 151  | 175  | 211  | 25   | 51   | 75   | 111  | 151  | 175  | 211  | 25   | 51   | 75   | 111  | 151  | 175  | 211  |
| Size (CM)    | 2    | 4    | 4,5  | 4,5  | 5    | 5    | 5,5  | 5    | 5    | 5,5  | 5,5  | 5,5  | 5,5  | 5,5  | 5    | 5    | 5    | 5    | 5,5  | 5    | 5    | 5,5  | 5    |

Figure 1. Plastic pipe with a label (in Russian)

nevertheless useful for reading damaged labels. In order to store a large amount of data bytes, the data should be divided into small parts where each part is represented by small-sized code.

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