# Smartphone Legibility of Laser Etched 2D Matrix Codes

## Optimizing smart phone legibility of laser etched 2D matrix codes with improved light trapping surface structures and tailor-made image processing algorithms

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Electronic identification of every single tire is a long standing request of the tire and automotive industry, as it facilitates downstream tire handling processes and helps increasing tire safety. However, the unique product properties of tires make this request a very difficult task: Printing or labeling are no durable options, as the complete outer surface of the tire is a wear-zone, in many instances being exposed to harsh climate conditions including UV radiation and constantly being stretched and compressed. Furthermore, the shielding properties of steel cord and carbon black make radio signals from inside the tire a complex and very expensive solution. Laser etching on the other hand is an industrial proven, robust and cost efficient process to individualize tires. However, so far it didn't provide sufficient contrast to allow for machine reading of 2D Matrix codes.

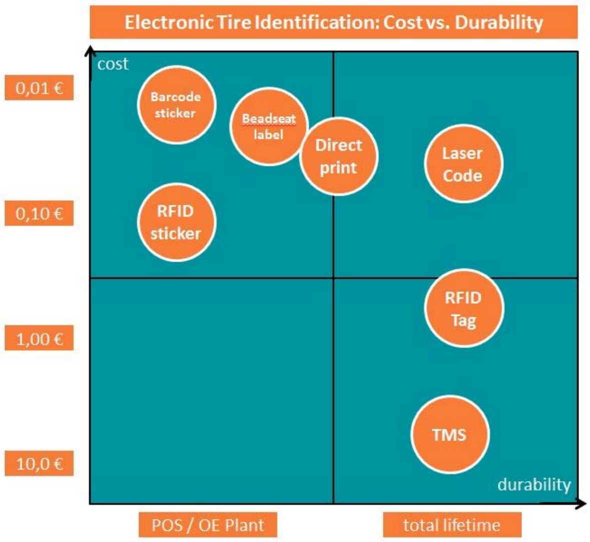


**Figure 1:** Cost lifetime comparison of different ID technologies (TMS = Tire Mounted Sensor, POS = Point of Sale)

Surface structuring to reduce light reflection is a long known principle. It is being applied e.g. for the technical realization of an ideal black body[i], to enhance the efficiency of solar cells[ii] or to increase optical contrast of design elements on tires[iii]. Surface structures in the dimension of a few hundred micrometers consisting of small dots and grooves with a high aspect ratio can be easily applied on a tire sidewall surface using laser etching. Such structures prevent direct reflection of visible light. Instead most of the light is "trapped" between the structure elements. A high percentage of the reflection can only take place indirectly after two or three reflection steps. As a result, the overall reflection can be reduced by a factor between 2.5 and 4. The structured surface appears "super-black" and the contrast between the original "tire

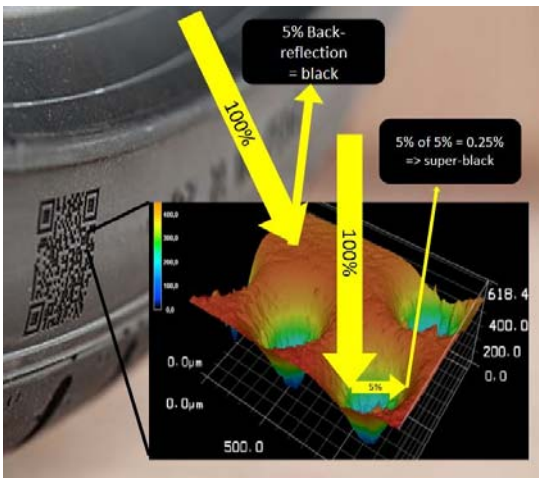


**Figure 2:** Working principle of a light trapping surface

black” and the “super-black” is sufficient to be detected even with the small camera systems of modern smart phones.

**Figure 3:** Typical QR captures from field testing. The codes are non-legible with ZXing however, could be de-coded after image pre-processing.

2D Codes prepared with this technique[iv] show reading rates of > 99.8% [v] conveyed under a sensor bridge[vi] or with a commercially available smart phone App[vii] for new tires. However, for tires in field use smart phone reading rates with such Apps drop significantly depending on wear, lighting conditions and contamination of the Code.

In order to understand the failure causes the open source de-coding engine ZXing was applied on non-legible QR Code captures and the failure mechanisms were analyzed. Based on the findings a number of tailor-made image pre-processing sequences were developed, that could transfer a non-legible QR Code capture into a legible one.

As an example in many cases the ZXing algorithm failed to properly find the threshold separating black from super-black caused by already tiny contamination with bright or shiny material, by uneven reflections e.g. from spot lights, by lighting gradients e.g. on curved tire surfaces or by a simple shadow border over the code. In this example pre-processing using Erosion/Dilation [viii] sequences are able to remove small contaminations like reflective sand grains from the QR code capture and Adaptive Thresholding [ix] allows determining the threshold under a lighting gradient.

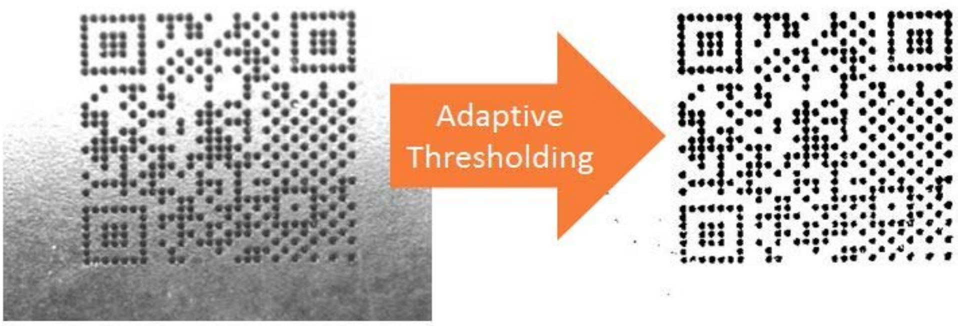


**Figure 4:** Adaptive Thresholding pre-processing transforms a grey-scale-image into a black and white image using a dynamically generated local threshold for each pixel.

In order to quantify the decoding results an extensive field study[x] was conducted; over 2.000 QR Codes on more than 500 truck, bus and passenger tires were tracked with a test App[xi]. De-coding rates for QR Code captures were compared using the ZXing only versus applying image pre-processing before using ZXing. According to the de-coding result QR Code captures were clustered into three groups: I. Permanent[xii] destruction or contamination, II. Temporarily non-legible (due to contamination or lighting conditions), III. Legible.

Permanent code failure happened a few times only and just for codes placed on the outer wear zone of the tire sidewall. For more protected codes near the rim of the tire no single permanent failure could be detected over a total of 30 Mio. Km. Hence, all well positioned codes could be read throughout the whole tire lifetime, for 3 % of the readings improving of lighting conditions or quick cleaning of the code became necessary.

| | | de-coding cluster | | |
|---|---|---|---|---|
| | | I. permanent destruction | II. temporarily non-legible | III. legible |
| Processing | code position | % of codes | % de-coding attempt | % de-coding attempt |
| ZXing only | wear exposed | 3.9 | 35.9 | 61.8 |
| | wear protected | 2.1 | 27.1 | 71.1 |
| Pre-processed | wear exposed | 0.1 | 4.2 | 95.8 |
| | wear protected | <0.0 | 3.3 | 96.7 |

**Figure 5:** Pre-processing strongly improves smartphone legibility in field testing. Temporarily non-legible codes could be read only after improving of lighting conditions or after cleaning with a damp soft cloth and wiping dry. Cluster I codes (destruction) permanently failed to be de-coded due to wear or un-removable contamination.

## Conclusion

Smart phone legibility of laser etched 2D matrix codes could be significantly improved using light trapping structures and enhanced image processing. Overall immediate reading rates of 96.7 % could be accomplished in an extensive field test. The vast number of parameters and low reproducibility of manual reading processes do not allow generalizing the results. However, they provide strong evidence, that this cost efficient, easy to implement technology is an alternative or even a complement to RFID, allowing direct access to the standard interface of everybody – the smartphone.

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[i] Lummer, O.; Kurlbaum, F. (1898). "Der electrisch geglühte "absolut schwarze" Körper und seine Temperaturmessung". Verhandlungen der Deutschen Physikalischen Gesellschaft. 17: 106–111.
[ii] P. Campbell, S.R. Wenham, M.A. Green, “Light trapping and reflection control in solar cells using tilted crystallographic surface textures”, Solar Energy Materials and Solar Cells, Volume 31, Issue 2, 1993, pp. 133-153
[iii] Paturle, A., Societe de Technologie Michelin: “Pneumatique avec marquage offrant une meilleure visibilite et procede de marquage”, Fascicule de brevet Europeen, EP 1 954 463 B1 (or US 2009/0218019 A1)
[iv] Performance measured for PCR tires with SCANNECT® QR Codes according to the AUDI/BMW Specification Car Tire Identification (specifications available at sales@4jet.de).
[v] Performance level limited by statistical restrictions: sample too small for proving higher rates
[vi] Performance measured with commercially available reading bar from Cognex, conveying speed 1m/s.
[vii] Performance measured with iPhone 7 and “QR Code Scanner” from Daniel Lulic, version 1.2.4
[viii] Jayaraman, Esakkirajan, Veerakumar: “Dilation- and Erosion-based Operations”, Digital Image Processing, 2009, pp. 554-555
[ix] Gonzalez, Rafael C. & Woods, Richard E. (2002). Thresholding in Digital Image Processing, pp. 595–611. Pearson Education. ISBN 81-7808-629-8
[x] Vehicles were used in mixed traffic and captures were de-coded in total more than 10.000 times over the lifetime of the tires.
[xi] SCANNECT® Test App is available in Apple AppStore and Google Playstore. Search for “tire scannect”.
[xii] Definition of “permanent”: Could not be read after cleaning with a damp soft cloth and wiping dry or after improving lighting conditions.