QRUco: Interactive QR Codes Through Thermoresponsive Embeddings

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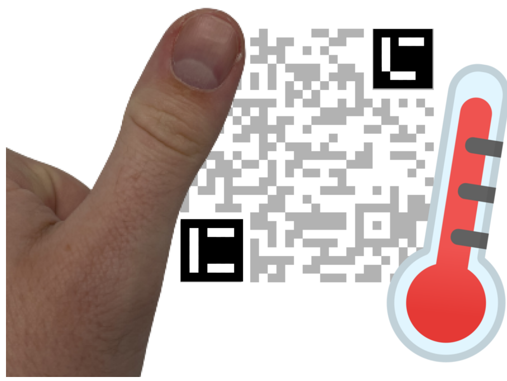

Figure 1: Image of a QRUco marker in use

ABSTRACT

Due to their low cost and ease of deployment, fiducial markers – primarily Quick Response (QR) codes – gained widespread popularity over the past decade. Given their original use cases in logistics, these markers were created with the goal of transmitting a single static payload. We introduce *QRUco* as an approach to create cheap yet interactive fiducial markers. QRUco uses thermochromic paint to embed three secondary markers into QR code finder patterns. Users may interact with these markers through rubbing or pressing/touching, thereby changing the appearance of the marker while leaving the primary QR code intact. In this paper, we present the QRUco concept and demonstrate that our proposed approach is effective. We emphasize that QRUco markers can be created cheaply and that they do not require any specialized scanning equipment. We furthermore discuss limitations of the proposed approach and propose application domains that would benefit from QRUco.

CCS CONCEPTS

• **Human-centered computing** → *Systems and tools for interaction design.*

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KEYWORDS

Interactive QR, Interactive Fiducial Markers, Passive Identification, Passive Interaction, ArUco

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1 MOTIVATION

Since their introduction in the year 1994 [4], Quick Response (QR) codes have become a widespread way of accessing information and websites for users. The information (often a URL) that is encoded in a QR code is static. To permit users to select among different options, they hence need to be presented with a selection mechanism on their user interface (typically a smartphone) *after* scanning a QR code. This means that to make any interactive selection based on a QR code, users today require an interactive device with a sufficiently capable user interface. Despite their origins in logistics and supply chain applications, which would profit from interactively changing markers as well (e.g., for tracking the state of products in cold chains), QR codes – and most other fiducial markers – today hence remain passive.

In this paper, we present an approach towards interactive QR codes that is compatible with standard QR codes. We propose that this might significantly broaden the area of application of QR codes in scenarios in human-computer interaction and in pervasive computing environments.

2 RELATED WORK

Linear barcodes are among the most widespread codes in our everyday surroundings, providing a cheap way of storing and exposing machine-readable information. These one-dimensional (1D) codes store information along a single axis and are standardized across many different symbologies (e.g., as Electronic Article Number / Universal Product Codes[1]). To increase information density, two-dimensional (2D) codes store information in two dimensions of pixels, each of which is referred to as a module. Because of their common usage in industrial settings, such as in logistics or in tracking individual components during manufacturing processes, these markers are required to maintain their information and remain readable under adversarial conditions, tolerating dirt, wear and tear, affine transforms during scanning, and other sources of noise. To address these issues, most 2D markers (including QR) use error-correcting codes (ECC) and other strategies to ensure the reliable transmission of information [4].

Like linear barcodes, 2D markers are typically non-interactive and display the same static code under varying circumstances. To make low-cost markers more interactable, Scheirer and Harrison proposed *DynaTags*, a method of changing markers before scanning [6]. Utilizing the ArUco marker standard [2], interaction is achieved by the user sliding, abutting, rotating, or hiding parts of markers. In their proposed solution they listed several use cases where such interaction before scanning could be helpful, however because of their usage of ArUco codes, a specialized scanning software needs to be used, as ArUco decoding is not as widespread as QR is; in addition, ArUco codes can store significantly less information than other standards such as QR. Guinard et al. [3] propose a dynamic tag comprising of a 2D barcode, which can change based on the environmental conditions the tag is exposed to. In their patent, functional inks (such as thermochromic ink) are mentioned and included as a way for a dynamic tag to alter the encoded data.

In addition to making fiducial markers responsive to user interaction, in our approach, we propose to embed responsive materials into widely accepted 2D marker standards, and concretely into QR codes. Coming from a security research background, Dabrowski et al. researched the possibilities of embedding one 2D code within another 2D code [1]. They were able to embed QR, Aztec and Data Matrix codes into a carrier QR code with varying degrees of success, which depended largely on the app or device used for scanning, as well as which type of code was embedded. Embedding QR codes into one another in a *steganographic* application was researched by Ohana and Shashidhar [5]. They embedded a secret message into a QR code, which when scanned would only reveal publicly accessible information. Only when in possession of a shared key consisting of the finder pattern of the hidden QR code in relation to the lower left finder pattern fixture of the parent code.

Informed by this related work, we propose an approach that permits standard QR codes to hold embedded secondary thermoresponsive ArUco markers as interactive elements.

3 QRUCO: INTERACTIVE QR CODES

With QRUco, our aim is to create a scheme that would permit the creation of a 2D code whose information can be changed through user interaction before scanning, e.g. by touching or rubbing on a part of the code. While this would hold advantages for end-user applications (e.g., to permit users to select a variant of a product before scanning it in a store), we believe that its potential lies with industrial applications (e.g., one-touch sorting of products in a warehouse) and with applications where the scanning device does not feature a sufficient user interface to permit selecting options after scanning. We propose a hierarchical scheme to accomplish this:

- Our *primary markers* are standard QR codes [4]. With up to 3 kB of storable information, these permit setting the context (e.g., a URL) when initially scanning a code, and they can be decoded with any standard QR scanner.
- Our *secondary markers* are created by embedding ArUco markers into the *QR Finder Pattern* (i.e., the three black squares in the code's top left, top right, and bottom left corners) using thermochromic paint.

The use of thermochromic paint (cf. [3]), together with our proposed embedding, form the essence of QRUco markers. With this specific combination, QRUco permits utilizing existing QR code scanners on mobile devices, where the interactive parameters are scanned in a second step.

3.1 Thermochromic Paint

Thermochromism describes the phenomenon of a material changing its wavelength-dependent light-scattering properties – and hence it's color – with changing temperatures [7]. Therefore, the human eye – as well as cameras – will perceive such paint as having a different color, depending on the temperature of the paint. The specific paint[2] that we used during the prototyping of QRUco markers transitions from black to white at approx. 15°C. If the paint is exposed to a lower temperature, it will (gradually) show as black, while it will turn transparent at higher temperatures, revealing the color underneath. To encode the modules of our secondary code, we applied the paint to a white background to utilize the full transition of the paint and allow the module to transition between black and white.

3.2 Secondary Markers

Similar to previous work [1, 5], we discarded the option of embedding interactive information within the code itself due to the QR code's ECC (i.e., Reed-Solomon [4]). While it would have been beneficial to preserve ECC, this would – in our use case – have required users to change (i.e., heat up) modules in multiple regions scattered across the code. When trying to distribute different options for interactions around the code, this would have required extensive thermal distribution and might have caused interference with other provided options. For this reason, we instead targeted the QR Finder Pattern – one of the most easily recognized elements of the code that offers a well-defined area for user interaction. We decided to use all three finder pattern structures in a QR code, resulting in the need for three different interactive markers that would fit with these areas.

[1] See https://www.gs1.org/standards/barcodes/ean-upc

[2] https://www.sfxc.co.uk/products/temperature-responsive-thermochromic-sprayable-coating

Figure 2: Images of ArUco markers being distributed within the finder pattern and permutations of which options can be detected.

Figure 3: The three ArUco markers that are used in our demonstrator, corresponding to ArUco IDs 257, 258, and 259.

Because of the aforementioned limitations encountered by others, requirements were collected that the embedded secondary markers would need to satisfy:

(1) Be detectable from the same distance as the main code to prevent reorientation issues.
(2) Preserve the general structure of the main code finder pattern as well as possible.
(3) Preserve the order in which the codes are detected: The secondary marker should not be detected first (cf. [1]).
(4) Require primarily local changes to modules to eliminate thermal distribution issues for color transitioning.

We selected *ArUco markers* as our prime candidate to satisfy all these requirements. These satisfy the QR standard's requirements *for the finder pattern*, namely the same size in modules (7×7), as well as a quiet zone around the outer border of black modules. Other options, such as *Aztec Code* and *Data Matrix*, might interfere with the third requirement: Based on the scanner used, these codes might be detected before or instead of the QR code [1]. On the other hand, since ArUcos are primarily used as orientation markers and not for encoding data, barely any scanning apps detect these markers. This benefits our approach, as we expect virtually no interference between QR scanning and ArUco scanning; and it is unlikely that apps for scanning ArUco markers would become widespread, as these markers are very hard to distinguish from other backgrounds (e.g., computer keyboards).

Based on three markers being present (or not) in the finder pattern structures of a QR code, eight (2^3) interactive parameters can be included in a QRUco marker: Each of the three markers can be touched/rubbed separately by the user, which makes the marker disappear. If no option was selected, meaning the code was scanned without prior interaction, all markers are detected, as shown in the leftmost marker in Fig. 2.

4 DEMONSTRATOR

Taking our approach into practice, we have implemented a working demonstrator of the QRUco concept. Our demonstrator uses three secondary ArUco markers that correspond to the IDs #257 (bottom left), #258 (top right) and #259 (top right) in the original ArUco dictionary (see Fig. 3). These IDs were chosen as they interfered with the QR finder pattern structures only a little and hence satisfy

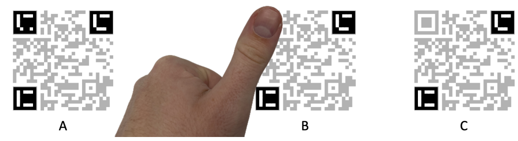

Figure 4: Transition of all secondary markers being present (A), the upper left finder pattern structure being warmed by touch (B), and the thermochromic paint of its embedded ArUco marker having transitioned from black to white (C).

our second requirement best. Orientation mattered neither for the ArUco codes nor for the detection of the QR codes.

To select a specific parameter using QRUco, the user heats up a single or multiple of the secondary markers, as shown in Fig. 4. There, a user heats up the top left marker with their thumb, which makes the ArUco code disappear. In our demonstrator, the user subsequently scans the QR code with a QR scanning application, which we have successfully tested with the iOS-included camera app (other apps are susceptible to the obstruction of the finder pattern structures to varying degrees). The scanning of the QR code reveals the content of the code to be a URL, which the user accesses.

In our demonstrator, once the user arrives at the encoded URL, they are asked for consent for the website to access the integrated camera based on device security settings. Once access has been granted, the JavaScript application on the website detects the ArUco markers present and routes to the URL that corresponds to the selected option. The detection of markers is done using a modified version of the *js-aruco2* library[3].

The practical tests of our demonstrator were conducted under lab conditions with an environment temperature of 5°C. This low temperature was required, as the specific thermochromic paint used in our prototype transitions from black to transparent at 15°C. This however does not represent a fundamental limitation of our approach: As publishers readily make use of thermochromic paint to reveal content only after touch in books[4], the specification of such ink can be altered to work in the intended way in realistic indoor settings as well. Another limitation of our demonstrator caused by the choice of paint is that only a transition from the color black to transparent can be achieved. To create a better contrast, the paint was applied on top of the printed QR code, which featured white modules underneath. This induces a transition from black to white when the elements were warmed. Based on the physical properties of this paint it however might also be possible to have a reverse transition, either by paint transitioning from white to black directly or from white to transparent, requiring the layer underneath to be black. This would be advantageous with respect to enabling any QR reader to detect the finder pattern, as the default option (without user interaction) in this case appears as a regular QR code.

[3] See https://github.com/damianofalcioni/js-aruco2
[4] See https://www.abprintgroup.com/heat-sensitive-printing/

5 DISCUSSION

While our demonstrator shows that QRUco markers can be successfully implemented, the concept also suffers from several limitations that we discuss in the following.

A potential limitation of QRUco is the required speed of users while interacting: Based on the time a user requires to scan a code after touching it, the thermochromic paint of the marker(s) might already have re-adjusted to the environment temperature. This means that the user's selection is then not recognizable by the camera anymore. Influencing factors to consider are the material on which the marker is applied and its thermal conductivity, as well as the environment temperature.

Another consideration is the usage of ArUco codes as secondary markers. While these provide an elegant way to utilize existing functionality for scanning and do not obstruct the QR finder patterns a lot, there might be a better-suited marker system. As the scanning of the secondary (ArUco) marker is decoupled from the initial scanning step, any other marker could be used instead of ArUco in principle, as long as it follows the requirements in Sect. 3.2. Based on the three structures of the finder pattern, the newly created marker system would only require three different markers or fewer, depending on the use case. These markers would again need to feature some of the properties that ArUco has, such as orientation invariance and the markers being easily distinguishable – any such marker system could be used, and alternatives might even be better suited for maintaining the original structure and integrity of the QR code finder pattern structures.

6 CONCLUSIONS

With QRUco we propose a new way of interactive low-cost fiducial markers, based on the physical properties of the paint used in a two-layered print. Our presented approach maintains all the benefits of a fiducial marker, such as low unit cost and high expressivity of the tag as well as high robustness, as we foresee that QRUcos could be created through well-established printing methods with added pigments of the thermochromic color.

Our proposed solution can be applied in various scenarios, as it merely provides a framework and leaves several parameters of the concrete implementation open to adjust to specific use cases. Based on our implementation, Web-based information services might be better primed for usage. The second scanning step can merely forward the user to the right option based on the detected markers. Prime examples of this can be menus with different sub-menus, which can already be pre-selected; multiple language options, which are available for a single website; or different payment and service options in a service setting, such as the restaurant. By shifting the interactive element to the fiducial marker, our concept is furthermore applicable in any setting where constrained interfaces are used to scan markers – here, we envision low-power, lightweight, non-interactive interfaces such as simple pen cameras that might be used in applications across private and industrial settings, for instance in logistics. Further, QRUco applies in pervasive computing settings where, either, users interact with QR codes that are scanned and further processed by other system components rather than by users themselves, and they can be used to track effects that the environment itself has on a tagged object: For instance, a tag's appearance would be modified when the ambient temperature in an environment exceeds a given temperature, which might be useful for instance in cold chain logistics.

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