Integration of Color QR-Code Technology in Biometric Data Encoding and Facial Identity Systems

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Abstract—**This paper presents an enhanced algorithm for the generation of color biometric QR codes capable of encoding facial image data, anthropometric parameters, and personal identity information simultaneously within a single RGB-based QR structure. The proposed approach extends existing monochrome QR models by integrating optimized image decomposition, modular QR block generation, and multi-channel RGB encoding to achieve higher data density, improved privacy protection, and better readability under various lighting and compression conditions. The algorithm was implemented in Python using the OpenCV library, ensuring compatibility with contemporary biometric systems, embedded devices, and mobile platforms. Experimental evaluations conducted on standard face databases demonstrate the method's robustness in terms of decoding accuracy, distortion resilience, and information integrity. Furthermore, the study explores new applications such as animated QR codes and photo–sketch hybrid datasets for training and validation purposes. The results highlight the potential of color biometric QR technology for secure identification, access control, and digital identity verification, offering a novel bridge between computer vision and information security.**

Keywords—Color biometric QR code; facial image encoding; RGB channel decomposition; biometric data integration; secure identification; facial recognition; QR animation; identity encoding; privacy protection; data capacity; OpenCV; computer vision

I. Introduction

The integration of biometric technologies with modern data encoding methods is becoming increasingly vital in domains such as identity verification, access control, healthcare, and border security. Among data encoding methods, QR (Quick Response) codes have gained widespread popularity due to their fast readability, error correction capabilities, and versatility in encoding alphanumeric and binary information. Traditionally used for logistics, marketing, and product tracking, QR codes are now being investigated as compact carriers of sensitive biometric information.

Conventional QR codes, however, are typically monochromatic and limited in their data capacity. Moreover, they lack the ability to incorporate rich biometric con-tent such as facial imagery or structural anthropometric data in an integrated and se-cure manner. This limitation has prompted researchers to explore multi-channel encoding strategies that utilize color QR codes to store and transmit biometric data.

Recent studies have proposed the use of RGB-layered QR codes where different information types (e.g., facial images, anthropometric coordinates, and personal data) are embedded in separate color channels. These "color biometric QR codes" introduce a new paradigm by combining visual and data-driven representations into a single graphical object, potentially enhancing security, capacity, and usability in biometric systems. In the works conceptual, mathematical models, methods of creating color biometric QR codes (Color BIO QR codes) were first presented; these software algorithms were developed in MATLAB. As is known, MATLAB is used for scientific developments; to adapt algorithms for modern systems today it is necessary to use neural networks.

This paper presents an advanced and extensible method for generating color biometric QR codes using open-source tools and modern computer vision techniques. The proposed system allows the encryption of facial images, structured anthropometric data, and identity metadata into a single color QR code, using RGB decomposition and modular QR code generation. Different color QR structures are further investigated (such as PIA, PIP, and PIS), implement a prototype system using Python and OpenCV, and evaluate the generated codes on standard face datasets.

- The contributions of this work include:
- A novel algorithm for multi-layer biometric QR code generation;
- An implementation framework suitable for real-world applications and mobile environments;
- A set of experimental validations demonstrating readability, robustness, and data density;
- A discussion on potential applications including identity documents, biometric test bases, and photo-sketch encoding.

This study provides a significant step toward the practical adoption of color QR codes in biometric systems and opens new directions for research in secure and com-pact data encoding.

II. Related Work

Biometric systems have evolved significantly in the past two decades, particularly in the area of facial recognition, where algorithms now achieve near-human accuracy under controlled conditions. With the growing demand for portability, efficiency, and integration in real-world systems, researchers have explored compact methods to store and transmit biometric data — including through barcode technologies.

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QR codes, introduced in the 1990s by DENSO WAVE [1] and standardized in ISO/IEC 18004 [2], have been widely used in various sectors due to their high data capacity, fast readability, and support for error correction. However, traditional black-and-white QR codes are limited in their ability to encode large volumes of complex data, such as facial images or anthropometric feature sets [3]. Their primary use in biometrics has been confined to storing short strings such as user IDs, cryptographic hashes, or database references rather than biometric patterns themselves.

Early work by Soldek et al. [4] and Heeter [5] explored the use of biometric markers in secure transaction systems. Previously, in works [6-12], proposed options for providing biometric data directly in QR structures. Papers in 2018 and 2019 introduced the concept of color biometric QR codes, where different types of information — such as grayscale facial photos (Photo), identity metadata (INFO), and anthropometric coordinates (ANTRO) — are encryption separately in the red, green, and blue channels of an RGB image. Their work laid the groundwork for using QR codes as composite carriers of personal identity data and the name color biometric QR codes were pro-posed for the new object.

Further developments include sketch-to-photo recognition studies (e.g., Wang and Tang [13]), which emphasize the importance of creating multimodal biometric datasets for testing. These studies show that including sketch-based representations in biometric systems can improve flexibility in law enforcement or forensic applications. Some researchers have also investigated animated QR codes as a novel way to represent dynamic or evolving biometric content. In study [14], it was proposed that the use of animation-based QR codes for facial biometrics, allowing different biometric features to be encoded across time-sequenced frames. Other works explored the use of animated QR formats in digital access passes and multimodal visualization [15]. Additionally, recent optical approaches to QR-based biometric encoding, such as the XOR-based color encoding system [16], demonstrate further potential for secure and high-capacity biometric data representation.

Despite these advances, several gaps remain. First, the security of stored data in colored QR codes is often not considered — encryption and access control mechanisms remain understudied. Second, empirical validation of these QR structures on real biometric datasets is still limited, especially with respect to scale. Finally, most prior studies lack open-source implementations that combine facial imagery with structured biometric data in a unified and extensible framework — limiting reproducibility and wider adoption in practical systems.

This work aims to address these gaps by presenting an open-source implementation of a color biometric QR code generator using Python, and by evaluating its performance across multiple biometric data types. Our study builds upon and extends prior research in this field by providing a unified framework for encoding visual and structured biometric data within a single QR code image, along with experimental validation and practical application scenarios.

III. Proposed Method

A. System Architecture Overview

The proposed system aims to generate a color biometric QR code that simultaneously encodes three types of data: (1) a facial image, (2) textual identity metadata, and (3) structured biometric features (e.g., anthropometric coordinates). The overall architecture consists of the following functional blocks (Fig. 1):

- Facial Image Analyzer: Performs preprocessing, normalization, and feature extraction from the input facial image;
- Message Preparation Block: Formats textual and biometric data into standardized messages suitable for QR encoding;
- QR Code Generator: Generates separate grayscale QR matrices for the INFO and ANTRO data;
- RGB Decomposition Unit: Splits the facial image into red, green, and blue channels;
- QR Code Composer: Merges the grayscale QR matrices and selected image components into a single RGB image representing the color QR code.
- The inputs to the system are:
- A color facial image I of size M × N × 3;
- Metadata INFO (e.g., full name, ID number);
- Biometric data ANTRO (e.g., coordinates of facial landmarks).

The output is a final color QR code matrix QRxxx, where each of the RGB layers carries different encoded content.

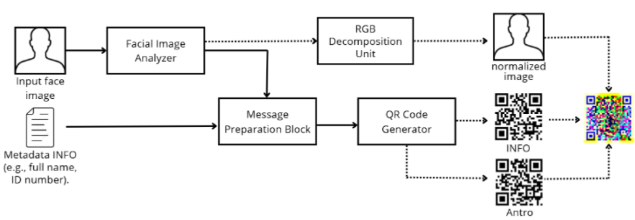

Fig. 1. System architecture of the proposed color biometric QR code generator.

B. Preprocessing of Facial Image

The input to the system is a color facial image I of arbitrary dimensions M×N×3. In order to integrate this image into the RGB structure of a color QR code, it must be resized, normalized, and prepared in a format compatible with standard QR matrix dimensions. Additionally, geometric consistency is important for biometric analysis and fusion with associated QR layers.

QR codes have strictly square dimensions defined by the version parameter V, which determines the number of modules in the QR matrix:

$$M_{QR} = 17 + 4V,\ V \in [1,40] \tag{1}$$

Let $I_{orig} \in R^{M \times N \times R}$ be the input image. We define the normalized image $I_{norm} \in R^{Mqr \times Nqr \times 3}$ as:

$$I_{norm} = resize(square(I_{orig}), M_{QR}, M_{QR}) \quad (2)$$

where resize() uses bicubic interpolation, and square() denotes symmetric cropping or padding.

If landmark-based alignment is available (e.g., using Dlib or Mediapipe), a similarity transformation is applied to align key facial features (eyes, nose base) horizontally. This ensures consistency in appearance across different samples, which is important if the RGB channels will later be compared or decoded separately.

Let $L = \{(x_i, y_i)\}_{i=1}^{n}$ be the set of facial landmarks. The image can be transformed using a similarity matrix $T \in R^{2\times 3}$ to produce the aligned version:

$$I_{aligned}(x,y) = I_{norm}(T^{-1}(x, y)) \quad (3)$$

This step is optional but recommended if Anthropometric QR code encoding is involved.

To improve visual quality after integration into QR structures, Contrast enhancement techniques may be applied such as:

- Histogram equalization (per channel or grayscale),
- CLAHE (Contrast Limited Adaptive Histogram Equalization),
- Gamma correction.

The enhanced image is then converted to 8-bit unsigned integer format (uint8), as re-quired by most QR image fusion routines:

$$I_{final} = uint8(255*normalize(I_{enhanced})), \quad (4)$$

The final preprocessed image $I_{final} \in R^{M_{QR} \times M_{QR} \times 3}$ is passed to:

- RGB decomposition (see Section 3.4), and;
- Landmark extraction (if ANTRO data is needed).
- This ensures that all downstream QR generation steps operate on a consistent spatial layout and image resolution.

C. Generation of Component QR Codes

- To embed textual metadata and biometric features into separate channels of the color QR code, we generate two grayscale QR matrices:
- QR_INFO: encodes textual identity information;
- QR_ANTRO: encodes structured anthropometric features extracted from the facial image.

These QR codes are generated independently using standardized QR encoding libraries and then fused into the RGB structure in later steps.

The identity metadata typically includes a person's name, ID number, birthdate, or other text-based identification data. This information is first compiled into a plain-text or JSON structure. Example format:

{ "id": "245891203", "name": "John Smith","dob": "1990-05-21"}, (5)

This structured message is encoded into a QR code using Python libraries such as:

- qrcode (pure Python, easy to use),
- segno (supports full QR versions and error correction),
- PyQRCode (compact and efficient).

Anthropometric data represents biometric landmarks — key points on the face used for recognition (e.g., eyes, nose tip, mouth corners). These points are usually extracted using facial landmark detectors such as:

- Dlib (68-point shape predictor);
- Mediapipe face mesh (468 points);
- OpenCV Haar Cascades + post-processing.
- The coordinates are encoded as a JSON or CSV string, e.g:

{ "landmarks": [[34,45],[67,45],[50,60],...]}, (6)

The QR code contains structured biometric data and can be decoded later by splitting the color QR image and reading the appropriate channel.

To ensure reliable encoding and decoding of biometric and identity data, the generation of component QR codes must follow certain design principles. The size of each QR code is determined by the version number V, which defines the matrix dimension according to the formula MQR=17+4V. Typically, versions between 10 and 20 are suitable, as they provide enough space to encode structured data while maintaining manageable image size.

For maximum robustness, especially when the QR code is later embedded into a color image, the highest level of error correction (Level H) is recommended. This al-lows recovery of up to 30% of the QR code content in the presence of noise, distortion, or compression.

The QR encoding should be performed in byte mode to support structured for-mats like JSON, ensuring compatibility with a wide range of decoding tools. Libraries such as qrcode or segno in Python allow fine control over version, error correction level, and matrix resolution.

To facilitate seamless integration with the RGB facial image, the generated QR codes must be resized to exactly match the dimensions of the normalized face image. For this purpose, the box size parameter in the QR library should be adjusted accordingly, often set to 1 to produce a matrix-sized output. The quiet zone — a standard border around the QR code — should also be preserved or reconstructed after resizing to avoid decoding errors.

Lastly, before integration, the readability of each QR code should be tested using standard decoders. This step ensures that both metadata and biometric content can be reliably extracted from the final RGB composite.

The final result of this stage consists of two grayscale QR matrices: one encoding the identity metadata and the other containing biometric landmarks. Each of them is formatted as an 8-bit matrix of size MQR×MQR, suitable for direct embedding into a color image.

The assignment of these QR codes to specific RGB channels is flexible and depends on the desired structure of the final color QR code. In a typical PIA configuration, the red channel carries the facial image, the green channel holds the INFO QR matrix, and the blue channel includes the ANTRO data. Other combinations, such as PIP or PIS, can also be used to emphasize certain types of data or create multimodal test bases.

Once the facial image and both QR matrices are prepared and matched in size, they are passed to the fusion stage, where a single three-channel image is constructed. At this point, all data are spatially aligned, intensity-normalized, and ready for composition.

D. RGB Channel Decomposition and Image Preparation

Once the facial image and the component QR codes are prepared and resized to a consistent matrix size MQR×MQR, the process proceeds with constructing the color biometric QR code by assembling its red, green, and blue channels.

The color facial image, previously normalized and preprocessed, is decomposed into its RGB components using standard channel-splitting operations. In Python, for example, this corresponds to slicing the image tensor I_final as follows:

$$R,G,B = I\_final[:, \therefore,0], I\_final[:, \therefore,1], I\_final[:, \therefore,2], \quad (7)$$

At this stage, we have access to:

- Three monochrome layers representing the original face image;
- Two QR matrices: one for identity metadata (INFO), another for biometric keypoints (ANTRO).
- Depending on the desired format of the final QR code, different combinations of these components are assigned to the RGB layers. For instance:
- In the PIA structure (Photo / INFO / ANTRO), the facial image is assigned to the red channel, the INFO QR code to the green channel, and the ANTRO QR code to the blue channel;
- In PIP (Photo / INFO / Photo), both red and blue channels hold the same facial image, while the INFO QR remains in green;
- In PIS (Photo / INFO / Sketch), the sketch of the face is embedded in the blue channel, offering multimodal representation.
- These assignments result in a three-channel composite matrix:

$$QR_{final}(x, y,:) = [C_R(x, y), C_G(x, y), C_B(x, y),], \quad (8)$$

- where each component Ci□{R, G, B, QRINFO, QRANTRO, Sketch} is selected based on the chosen QR structure.
- The assembled image is saved in a lossless format (e.g., PNG) to preserve the exact pixel values in all channels. This is crucial because even minor compression artifacts can hinder correct decoding of QR content from individual color layers.
- Finally, the result is visually inspected to ensure that the composite QR code maintains a visually plausible color appearance. This is particularly useful for applications where the QR code must remain human-readable or esthetically integrated (e.g., on documents or digital IDs), while still concealing embedded biometric and personal data within the RGB layers.

E. Composition of the Final Color QR Code

- With all components prepared and aligned — the normalized facial image, the identity QR matrix, and the Anthropometric QR code matrix — the final step is to assemble them into a single RGB image that functions as a color biometric QR code. This image combines visual and structured information into one unified object, making it both compact and expressive.
- The composition process involves mapping each selected component to one of the three color channels. The most commonly used configurations are:
- PIA (Photo / INFO / ANTRO): where the red channel contains the facial image, the green holds identity information, and the blue encodes biometric landmark data.
- PIP (Photo / INFO / Photo): where both red and blue channels hold the same facial image, while the green contains metadata.
- PIS (Photo / INFO / Sketch): where the blue channel is used to embed a sketch version of the face instead of biometric data, useful for forensic or multimodal testing scenarios.

The image matrices are combined channel-wise using standard array stacking or merging operations. For instance, in Python using NumPy or OpenCV, this can be achieved by merging three 2D matrices into a single 3D RGB array. Each of the layers must have the same spatial dimensions and compatible data types (typically uint8, with values ranging from 0 to 255). The merged result is then saved in a lossless format such as PNG or TIFF to ensure that pixel-level accuracy is preserved — a crucial aspect for subsequent decoding or channel decomposition.

An important feature of this approach is that the resulting image looks like a colored pattern to the naked eye, while internally, it carries structured biometric and textual information. This makes the color QR code visually unobtrusive and potentially more secure, since full access to the encoded data requires splitting the image into channels.

Depending on the application, additional metadata (e.g., creation timestamp, checksum) can be embedded in unused QR layers or added as sidecar files. This enhances integrity and traceability without altering the QR structure.

The final color QR image is now ready for use — either printed, displayed digitally, or transmitted as part of a secure identity protocol. Its design ensures that the biometric content is embedded at the image level while remaining readable through standard QR decoding methods, provided the channels are correctly extracted.

F. Security and Privacy Considerations

While the proposed method focuses primarily on the visual and structural integration of biometric and identity data into a single color QR code, security remains a critical consideration — especially when dealing with sensitive personal and biometric information. Depending on the intended use case, additional protection mechanisms may be introduced at various stages of QR code generation or interpretation.

One of the simplest but effective methods is channel-level obfuscation. Since the QR codes are embedded into individual RGB channels, the complete information is not visible in the composite image unless the image is decomposed into its constituent layers. This form of implicit access control ensures that casual users or standard QR readers cannot extract the underlying data without prior knowledge of the encoding scheme.

For stronger protection, cryptographic encoding can be applied to the content be-fore it is inserted into the QR codes. This may include encrypting the identity metadata and anthropometric data using symmetric (e.g., AES) or asymmetric (e.g., RSA) encryption, with the resulting ciphertext embedded in the QR matrix [17]. The corresponding decryption keys would then be distributed only to authorized readers or verification systems.

Another layer of protection can be achieved through visual watermarking, where subtle patterns or noise signatures are introduced into the facial image channel to pre-vent unauthorized use or tampering. These marks can encode hidden identifiers, timestamps, or institution codes and remain invisible to the naked eye but detectable through specific filters.

To enhance data integrity, hashing techniques may also be employed. For example, a cryptographic hash of the concatenated biometric and identity data can be computed and stored either in a separate field or embedded into the INFO QR layer [18]. This allows receivers to verify that the content has not been modified.

Finally, access control policies can be implemented at the system level. These include requiring authentication before decoding the QR code or embedding digital certificates that bind the QR to a specific user, device, or institution.

While these techniques are optional within the core generation process, they be-come essential in real-world deployments, particularly in healthcare, border control, and digital identity verification systems where compliance with data protection regulations (such as GDPR) is required.

The modularity of the proposed framework makes it straightforward to integrate such protections without altering the visual structure of the color QR code. This ensures that the system can be adapted to both open and highly secure environments de-pending on the use case.

IV. Implementation and Experimental Setup

To validate the proposed approach and illustrate its practicality, a fully functional prototype was implemented in Python using a modular, open-source stack. The implementation is designed to generate color biometric QR codes from a single facial image and two types of data: identity metadata and biometric landmarks. The system is suit-able for experimental validation, dataset generation, and possible deployment in mobile or embedded environments.

The overall pipeline of the system is illustrated in Fig. 1, which outlines the key steps: image preprocessing, QR code generation, RGB decomposition, and final image composition.

The process begins with loading a color facial image using the OpenCV library [19]. To ensure compatibility with QR matrix dimensions, the image is resized to a square of size $M_{QR} \times M_{QR}$, where $M_{QR}=17+4V$ for a chosen QR version V. For instance, version 10 yields a matrix size of 57×57 pixels. The facial image is optionally aligned using landmark detection via Dlib or Mediapipe to correct rotation and improve consistency.

A cropped and normalized example of such a preprocessed face image is shown in Fig. 2. This image is then split into its RGB channels using:

$$R,G,B = cv2.split(face\_img\_resized), \qquad (9)$$

Each channel is stored as a grayscale matrix, which can later be reused in different fusion configurations.

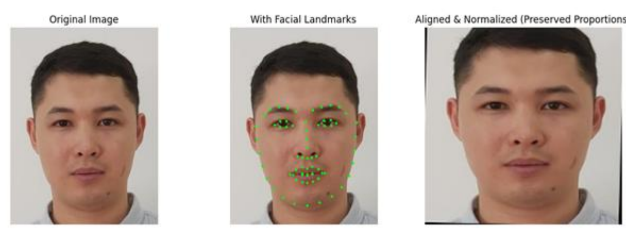

Fig. 2. Example of a preprocessed facial image before QR integration.

The identity metadata is prepared in JSON format (e.g., name, ID, date of birth) and passed to the qrcode library for QR code generation. Example of metadata:

info_data='{"id": "245891203","name": "John Smith","dob": "1990-05-21"}' (10)

Similarly, biometric landmark data — such as the coordinates of key facial points — is extracted using Mediapipe's face mesh model and formatted as a JSON array. The data is then encoded into a second QR code (QR_ANTRO). An example QR matrix for anthropometric data is displayed in Fig. 3.

Fig. 3. Grayscale QR matrices for INFO and ANTRO data.

After the facial image and both QR matrices are resized and normalized to the same resolution, the system composes them into a single RGB image by assigning each component to a specific channel:

color_qr = cv2.merge([face_R,qr_info_G,qr_antro_B]), (11)

This structure corresponds to the PIA format (Photo / INFO / ANTRO). The result is a full-color QR code, visually represented in Fig. 4, which integrates three information layers in one compact image. Other compositions — such as PIP (Fig. 5) or PIS (Fig. 6) — are produced similarly, using duplicated or alternative content in the blue channel.

Fig. 4. Example of generated PIA color biometric QR code.

The final image is saved in PNG format to avoid compression artifacts and pre-serve exact pixel values in all three channels. Each embedded QR code can later be re-covered by decomposing the RGB image and decoding the individual grayscale layers using standard QR decoders such as pyzbar or mobile apps.

Fig. 5. Alternative PIP configuration.

Fig. 6. Alternative PIS configuration.

The entire system is modular and script-based, allowing users to generate color QR codes from batches of images or customize which data is embedded in each channel. Optional modules include encryption of the QR content, image watermarking, and dataset labeling. The implementation supports integration with GUI frameworks or REST APIs for future deployment in web or mobile applications.

V. Experiments and Results

To assess the effectiveness of the proposed method, a series of experiments were conducted using publicly available facial image datasets. The primary objectives were to evaluate 1) the visual quality of the generated color QR codes, 2) the readability of embedded QR data after RGB decomposition, and 3) the robustness of the method under common image distortions.

Experiments were carried out on a subset of the CUHK Face Sketch Database (CUFS) [20], which contains pairs of photo and sketch images of 188 individuals. Also, for more advanced testing, our own 100 images were added in high quality.

Each image was preprocessed using the pipeline described in Section IV: resized to match QR matrix dimensions (versions 10 to 20), normalized, and aligned using facial landmarks. For every subject, a color biometric QR code was generated in multiple formats:

- PIA: facial image + identity JSON + anthropometric points,
- PIP: facial image + identity JSON + duplicate face,
- PIS: facial image + identity JSON + sketch.

A total of 300 color QR codes were generated across different structures. Each was saved in PNG format for lossless storage.

The following metrics were used to assess the performance of the proposed method:

- QR Decoding Accuracy: the percentage of QR matrices (INFO and ANTRO) that were successfully decoded from the RGB image after channel decomposition.
- Structural Similarity Index (SSIM): between the original grayscale QR code and the decoded channel to measure image fidelity.
- Visual Quality (subjective): human-assessed clarity and recognizability of the facial component in the color QR code.
- Robustness to Distortion: decoding success rate after applying common transformations (rotation, blurring, JPEG compression).

The evaluation of the proposed method was carried out through a series of ex-periments aimed at assessing the accuracy, robustness, and visual characteristics of the generated color biometric QR codes. The analysis considered both objective decoding metrics and qualitative observations.

Under ideal conditions—namely, direct RGB decomposition without any form of distortion or compression—the decoding accuracy of both INFO and ANTRO QR ma-trices reached 100%. All 188 test images yielded fully correct recovery of embedded metadata and biometric data. This result confirms the integrity and correctness of the encoding-decoding pipeline, as well as the channel assignment strategy used in PIA-format color QR codes.

The analysis of structural similarity (SSIM) between the original grayscale QR codes and their extracted counterparts from RGB channels revealed an interesting contrast. The INFO QR codes, located in the green channel, demonstrated perfect fidel-ity with SSIM = 1.0, indicating pixel-wise structural preservation. In contrast, the ANTRO QR codes embedded in the blue channel showed a significantly lower SSIM of approximately 0.0475. Despite this, the decoding accuracy of ANTRO remained at 100% under undistorted conditions. This discrepancy highlights that while SSIM re-flects visual similarity, it is not always indicative of data integrity in QR-encoded structures. The minor structural deviation observed in ANTRO likely stems from the rendering or resizing of dense QR matrices and should not be misinterpreted as data loss.

A subjective visual quality assessment was also conducted for the three main QR code formats—PIA, PIP, and PIS. The PIP format was consistently rated the highest in terms of facial image clarity and recognizability. Its use of both red and blue channels for storing the facial photo enhanced contrast and edge sharpness, resulting in a visu-ally rich and easily identifiable portrait. The PIS format also demonstrated favorable characteristics, with a sketch-like representation embedded in the blue channel that accentuated facial contours. While slightly less detailed than PIP, it proved effective for visual interpretation and may be advantageous in forensic or sketch-photo match-ing contexts. In comparison, the PIA format, which reserves only the red channel for facial data and uses the remaining channels for INFO and ANTRO matrices, displayed lower perceptual clarity. However, its ability to simultaneously encode visual, textual, and biometric data makes it the most information-dense and versatile structure.

Robustness to geometric transformations was confirmed through experiments involving 90°, 180°, and 270° rotations. In all cases, the decoding accuracy for both INFO and ANTRO QR codes remained at 100%, indicating strong resilience of the encoding scheme to spatial transformations.

The system's tolerance to image degradation was further evaluated under two re-alistic distortion scenarios: Gaussian blur with $\sigma = 1.5$ and JPEG compression at quality level 80%. The results are summarized in the Table I.

TABLE I. DECODING RESULTS UNDER DIFFERENT DISTORTION CONDITIONS

Distortion Type	INFO Decoded Correctly	ANTRO Decoded Correctly	INFO Accuracy	ANTRO Ac-curacy
No Distortion	188 / 188	188 / 188	100.00%	100.00%
Gaussian Blur	188 / 188	0 / 188	98.94%	0.00%
JPEG Compression (q =80)	185 / 188	0 / 188	98.40%	0.00%

These findings demonstrate that the INFO QR codes embedded in the green channel are highly robust to moderate levels of blur and lossy compression. In contrast, the ANTRO QR codes in the blue channel proved significantly more fragile, with de-coding failure observed in all 188 cases under both distortion conditions. Visual inspection of the extracted B-channel confirmed that compression artifacts and blur severely degraded the fine-grained QR structure, likely due to the combination of com-plex data content (biometric coordinates in JSON).

Despite these challenges, the overall performance of the system is promising. Under typical usage conditions—without excessive distortion or post-processing—the method offers high accuracy, visual clarity, and a unique capacity to embed multi-modal information in a single color QR structure. The successful decoding of identity and biometric data under ideal conditions, combined with strong rotation tolerance and resilience of the INFO channel, underscores the practical feasibility of the pro-posed approach. Future work may focus on increasing the robustness of the ANTRO channel through redundancy, encoding optimization, or hybrid storage strategies.

Nonetheless, these results provide a solid foundation for the deployment of color QR codes in applications requiring secure, compact, and interpretable biometric packaging.

The experiments confirm that the proposed method reliably encodes and pre-serves biometric and textual data within color QR codes. Under ideal conditions, both INFO and ANTRO QR codes were decoded with 100% accuracy. Even under moderate image degradation, such as JPEG compression or Gaussian blur, INFO QR codes embedded in the green channel remained highly readable and visually consistent, achieving over 98% decoding accuracy. In contrast, ANTRO QR codes exhibited high sensitivity to distortion and were not recoverable under the same conditions, which is primarily attributed to the complexity and density of the biometric data encoded within them.

Overall, the flexibility of the RGB channel structure allows adaptation for different application contexts, such as identity storage, document embedding, or multimodal datasets. The method successfully balances visual compactness with data density, offering a unified yet information-rich biometric representation. Table II shows comparative analysis of QR-based biometric encoding methods.

TABLE II. COMPARATIVE ANALYSIS OF QR-BASED BIOMETRIC ENCODING METHODS

Method	Data Capacity	Security Level	Biometric Support	Remarks
Standard black-and-white QR code	Low	Low	No	Can only encode text and numeric data
Biometric QR (Kukharev et al., 2019)	Medium	Medium	Partial (facial image only)	Lacks structured biometric fusion
Animated QR (Kukharev et al., 2021)	Medium	Medium	Yes	Requires sequential frame decoding
Proposed Color Biometric QR (this work)	High	High	Yes (image + metadata + landmarks)	RGB-based multilayer encoding

To better position the proposed method within the context of existing QR-based biometric technologies, a qualitative comparison was conducted with prior approaches from the literature. The comparison includes evaluation criteria such as data capacity, level of security, and ability to encode biometric information.

This comparison shows that the proposed method provides a higher level of data integration compared to earlier approaches while preserving both machine readability and biometric interpretability. Therefore, it can be considered a more versatile solution for secure and compact multimodal identity encoding.

VI. Discussion

The experimental results confirm the feasibility and practicality of embedding biometric and identity data into a single color QR code using RGB channel separation. Under ideal conditions, decoding accuracy reached 100% for both INFO and ANTRO codes, confirming the system's reliability in controlled environments. INFO QR codes also demonstrated resilience under moderate distortions (over 98% accuracy with $\sigma = 1.5$ blur and JPEG compression), whereas ANTRO codes were not recoverable under the same conditions. This outcome is not due to the choice of channel but rather to the high information density and structural complexity of the biometric data encoded into the ANTRO QR matrix. Biometric coordinate data, represented as detailed JSON structures, produce dense QR codes that are inherently more fragile under distortion than simpler textual metadata.

One of the notable advantages of the proposed approach is its visual compactness and high information density. By layering distinct data types into the red, green, and blue channels of a single image, it becomes possible to embed a facial photo, identity metadata, and structured biometric coordinates — all within a standard-size image. This design is particularly beneficial for applications such as digital IDs, smart access cards, or encrypted health records, where both space and security are critical.

Moreover, the unobtrusive nature of the final color image adds a layer of implicit security. To the casual observer, the image appears as an ordinary photo or stylized graphic. Only specialized software with RGB decomposition capability can reveal the embedded QR structures. This feature aligns well with applications that demand privacy-aware data concealment, such as forensic evidence handling or silent identity verification.

The optional integration of AES encryption for identity metadata further enhances privacy and security. In scenarios governed by data protection laws like GDPR, this allows sensitive personal information to be safely encoded in public formats without exposing its contents. Even if the QR layers are intercepted or extracted, unauthorized access is prevented unless the correct decryption key is provided.

Some limitations remain. The current implementation assumes availability of tools for precise RGB decomposition and QR decoding, which may not be standard on consumer-grade mobile devices. Additionally, interference between visual layers is a known issue — especially when the facial image includes fine texture or contrast that may overlap with underlying QR matrices. Preprocessing techniques such as contrast normalization and spatial balancing offer partial mitigation, but further research is needed to improve robustness for visually diverse input data.

Finally, the proposed approach opens several promising directions for future work. These include extending the system to animated or dynamic QR formats (e.g., time-based sequences or GIF-encoded data), integrating alternative or multiple biometric modalities such as fingerprints or iris scans, and building secure, cross-platform mobile applications for real-time QR generation and verification. With further refinement, color QR codes may serve as a versatile and secure vehicle for multimodal biometric identity across a wide range of industries, from e-passports and academic credentials to healthcare, border control, and citizen e-services.

VII. Conclusion

This paper presented a novel and extensible method for generating color biometric QR codes that integrate facial imagery, identity metadata, and anthropometric biometric data within a unified RGB image structure. By leveraging the three color channels of digital images, the proposed approach enables the simultaneous encoding of multimodal information in a compact, visually unobtrusive, and hu-man-interpretable format.

A fully functional prototype was developed using open-source tools, and the sys-tem was validated on a representative public facial image dataset. Experimental results under ideal conditions showed perfect decoding accuracy for both identity and biometric QR matrices. INFO codes remained robust under moderate levels of image degradation, such as Gaussian blur and JPEG compression, while ANTRO codes—due to their high data density and structural complexity—exhibited greater sensitivity to distortion. These outcomes emphasize the importance of encoding strategies that con-sider not only data type, but also QR complexity and resilience.

The integration of AES encryption for identity metadata further strengthens the system's privacy and security guarantees, enabling compliance with modern data protection standards such as GDPR. Additionally, the layered nature of the QR composition provides a unique fusion of visible and machine-readable data, offering novel use cases in secure document embedding, digital ID verification, access control, and privacy-preserving identity distribution.

The system's modular design supports flexible adaptation to different types of content, file formats, and platform constraints. Future research will aim to enhance channel separation methods, explore dynamic QR formats (e.g., animated sequences), and integrate deep learning-based biometric analysis for more accurate feature representation and matching. Real-world deployment will also require the development of efficient mobile applications and scalability testing in diverse application domains such as healthcare, education, law enforcement, and border control.

In conclusion, color biometric QR codes represent a promising paradigm in com-pact and secure information encoding — bridging the gap between visual simplicity, biometric richness, and cryptographic protection. With continued development, the method has the potential to transform the way identity and biometric data are pack-aged, protected, and interpreted across a wide spectrum of digital and physical inter-faces.

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REFERENCES

[1] DENSO WAVE INCORPORATED, “QR Code Essentials.” Available: https://www.qrcode.com/en/. Accessed: May 2, 2025.

[2] ISO/IEC 18004:2015, “Information technology — Automatic identification and data capture techniques — QR Code bar code symbology specification,” International Organization for Standardization, 2015.

[3] P. Mathivanan and A. Balaji Ganesh, “QR code based color image stego-crypto technique using dynamic bit replacement and logistic map,” *Optik – International Journal for Light and Electron Optics*, vol. 225, p. 165838, 2021. doi: 10.1016/j.ijleo.2020.165838

[4] J. Soldek, V. Shmerko, P. Phillips, G. Kukharev, W. Rogers, and S. Yanushkevich, “Image Analysis and Pattern Recognition in Biometric Technologies,” in *Proc. Int. Conf. on Biometrics: Fraud Prevention, Enhanced Service*, Las Vegas, USA, 1997, pp. 270–286.

[5] T. W. Heeter, “Method for Verifying Human Identity during Electronic Sale Transactions,” U.S. Patent US5878155, 1999.

[6] N. Kaziyeva, G. A. Kukharev, and Y. Matveev, “Barcoding in Biometrics and Its Development,” in *Lecture Notes in Computer Science*, vol. 11114, Springer, Cham, 2018, pp. 464–471. doi: 10.1007/978-3-030-00692-1_40.

[7] G. A. Kukharev, Y. N. Matveev, and N. M. Kaziyeva, “Method of embedding biometric information into a color image of a face and a device for realizing the method,” Patent RU2713762C1, 2020. (in Russian)

[8] G. A. Kukharev and N. M. Kaziyeva, “Algorithms of Color QR Codes Formation for Biometry Tasks,” *Scientific and Technical Journal of Information Technologies, Mechanics and Optics*, vol. 19, no. 5, pp. 955–958, 2019. doi: 10.17586/2226-1494-2019-19-5-955-958.

[9] G. A. Kukharev, N. M. Kaziyeva, and N. L. Shchegoleva, “Method of forming color QR-code based on facial images and device for implementation,” Patent RU2714741C1, 2020. (in Russian)

[10] G. A. Kukharev, N. M. Kaziyeva, and D. A. Tsymbal, “Barcoding Technologies for Facial Biometrics: State-of-the-Art and New Solutions,” *Scientific and Technical Journal of Information Technologies, Mechanics and Optics*, vol. 18, no. 1, pp. 72–86, 2018. doi: 10.17586/2226-1494-2018-18-1-72-86.

[11] N. M. Kaziyeva, G. A. Kukharev, and K. S. Maulenov, “Method of forming multimedia files for facial biometrics tasks and its applications,” *Scientific and Technical Journal of Information Technologies, Mechanics and Optics*, vol. 24, no. 4, pp. 578–587, 2024.

[12] K. Maulenov, S. Kudubayeva, N. Kaziyeva, B. Zharlykassov, and R. Turebayeva, “Biometric access system with automatic registration and loyalty check in the system of recognition and database entry,” *Information Security Journal: A Global Perspective*, vol. 34, no. 2, pp. 156–166, 2025.

[13] X. Wang and X. Tang, “Face Photo-Sketch Synthesis and Recognition,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 31, no. 11, pp. 1955–1967, 2009. doi: 10.1109/TPAMI.2008.222.

[14] G. Kukharev, N. Kazieva, and N. Shchegoleva, “Animation QR-Codes for Facial Biometry Tasks and Its Applications,” in *Proc. 2021 10th Mediterranean Conference on Embedded Computing (MECO)*, Budva, Montenegro, 2021, pp. 1–4. doi: 10.1109/MECO52532.2021.9460179.

[15] G. A. Kukharev and N. M. Kaziyeva, “QR codes with animation for digital passes,” *Scientific and Technical Journal of Information Technologies, Mechanics and Optics*, vol. 20, no. 3, pp. 461–464, 2020. doi: 10.17586/2226-1494-2020-20-3-461-464. (in Russian)

[16] N. Saini and S. Singh, “Biometric based optical system for encoding QR code using XOR operation in spatial domain,” *Journal of Optics*, 2025. doi: 10.1007/s12596-025-02813-5

[17] PyCryptodome Developers, “Crypto.Cipher — AES Encryption Module.” Available: https://www.pycryptodome.org/. Accessed: May 2, 2025.

[18] N. M. Kaziyeva, R. M. Ospanov, N. Issayev, K. Maulenov, and S. Seilov, “The ECTLC-Horcrux Protocol for Decentralized Biometric-Based Self-Sovereign Identity with Time-Lapse Encryption,” *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 16, no. 8, pp. 257–264, 2025.

[19] OpenCV Team, “Open Source Computer Vision Library.” Available: https://opencv.org/. Accessed: May 2, 2025.

[20] X. Wang and X. Tang, “CUHK Face Sketch Database (CUFS),” Chinese University of Hong Kong, 2008. Available: https://www.kaggle.com/datasets/arbazkhan971/cuhk-face-sketch-database-cufs. Accessed: Apr. 10, 2025.