ColorCodeAR:

Large identifiable *ColorCode*-based augmented reality system

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***Abstract*— Augmented reality (AR) is widely used in various applications of computer vision, such as marker-based AR and markerless-based AR. These AR techniques are used in various fields, including industry, education, and medicine. Using marker-based AR, employees can easily perform step-by-step maintenance and repairs, and they can register parts information for large plants. However, conventional marker-based AR relies on a relatively small number of recognizable IDs compared to barcode markers. In this paper, to address the insufficient identification volume in conventional AR systems, we integrate barcode-based code technology with marker-based AR technology. Based on the results of an experiment, we applied *ColorCode* to our marker-based AR system. Nevertheless, difficulties arise when applying *ColorCode* to an AR system, owing to its recognition distance and relatively small size, compared to other AR codes. In this paper, therefore, we complemented quad detection with a tracking technique for various angles and distances, facilitating reliable recognition of the color-code-based AR system, Moreover, we added a tracking module to address the system's failure to detect markers. The experimental results demonstrate that the proposed system offers stable recognition.**

I. Introduction

Augmented reality (AR) is an increasingly significant area of research, with wide-ranging applications in various fields, including industry, education, and medicine. AR techniques can be broadly divided into two approaches: marker-based AR[3, 4, 5, 9, 10, 11], and markerless-based AR[21, 22, 23, 24]. With marker-based AR, for example, images (or the corresponding image descriptors) are provided beforehand, and users must know exactly what the application should recognize when a camera acquires an image. By contrast, markerless-based AR recognizes images that are not provided to the application beforehand. This technique accounts for the local features and characteristics of a video by performing interest-point object detection. As such, markerless-based AR can be used to identify patterns, colors, and other features.

Marker-based AR typically involves using a template-tracking technique for easy recognition and tracking. This does not require considerable computational resources, and an accelerometer on the user's device can be used to perform the recognition. For this reason, among diverse applications, there is increased demand for marker-based AR for maintenance in industrial plants. Without the use of marker-based AR, maintenance staff must be highly knowledgeable and skilled, and it is difficult to maintain such employees in plants. To solve this, AR technology has been developed such that non-experts can perform these maintenance tasks. With marker-based AR, it is easy to register and manage maintenance and parts information in large-scale factories. With AR, employees can easily perform step-by-step maintenance and repairs, and they can register parts information in large plants.

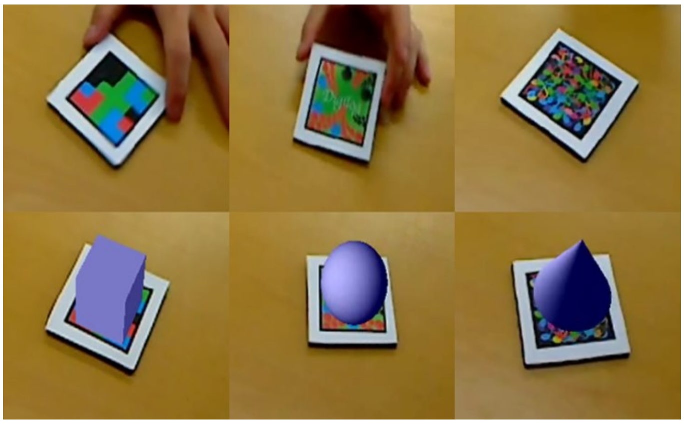

Figure 1. *ColorCodeAr*:Color barcode based AR

Marker-based recognition technology is broadly divided into barcode-based code technology [3, 4, 5, 7, 8] and AR marker technology [9, 10, 11, 12, 13, 14]. With first-generation 1D barcodes such as the universal product code (UPC) or European article numbering (EAN), black lines of differing thickness arranged in different intervals on white backgrounds are converted into binary code to recognize them. 1D barcodes are easily recognized, because their design is simple. However, these barcodes can express only limited information, and the density of the recorded information is low. Thus, the size of the code must be increased in order to express more information.

2D barcodes include the following: Denso's *QR codes* [3], which can quickly be deciphered by their finder patterns; Symbol Technologies' *PDF417* [4], which has a high damage-recovery rate; International Data Matrix's *Data Matrix* [5], which can be made into ultra-small squares with high-density records; UPS's *Maxi Code* [6] and Zebra's *Ultracode* [7], both developed for rapid delivery; and ColorZip Media's *ColorCode* [8], which uses sloping patterns at 45° angles. The advantages of these 2D barcodes over 1D barcodes stem from their ability to handle more data and more data types with a higher density of information.

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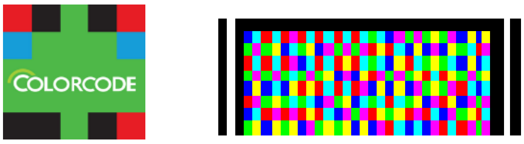

(a) ColorCode (b) Ultracode

Figure 2. Third-generation 2D color barcode

Among these 2D barcodes, *ColorCode* and *Ultracode* use colors to express more information on the same surface. However, this barcode-based code technology is designed for single tags in the image, and since it assumes nearby recognition, it does not respond well to distortions or changes in scale.

Table I. VARIOUS TYPE OF BARCODE-BASED CODES

Code type	**Feature**	**type**
First-generation 1D barcode	Speed, Accuracy	EAN, UPC, Codabar, etc.
Second-generation 2D barcode	capacity, Speed, Error recovery	QR code, Maxi code, etc.
Third-generation 2D color barcode	Design, Mobility	ColorCode, Ultracode, etc.

Several AR markers have been proposed that are resistant to distortions or changes in scale, unlike image codes designed for single tags. Because the former allow for continuous interactions, a more tangible interaction is possible than with the latter. *ARToolKit* [9] recognizes image patterns registered on a wide rectangular border to support some 100 IDs. Because *ARToolKit* uses the template-matching method, its recognition rate varies according to the internal ID's pattern shape. According to [17], *ARToolkit* can distinguish between 21 markers. Moreover, it can detect and decode a marker of 14 × 14 pixels from a 320 × 240 image. Yet, if the number of markers increases, inter-marker confusion also increases, degrading the recognition rate. Normally, a stable recognition rate is only possible with 30 or fewer markers.

ARToolKitPlus [11] added the possibility of switching to ID-encoded marker detection, rather than the built-in template matching [20]. This allows for the use of up to 512 different markers without training and without a reduction in speed, resulting in a speedup even when only one marker is used. ID-encoded marker detection is generally faster than using template (image) markers. However, with BCH markers, 4,096 markers are supported.

ARTag [10] calculates an optimized set of hamming distance histograms to determine the optimal ID set. It further removes 44 confusable IDs from within a total of 2,046, to support 2,002 IDs. The markers proposed in [13] have a reduced marker area, making them unobtrusive. These markers are designed such that human-readable images can be inserted while retaining a free area on the inside. With *ARTag*, 512 frame markers and 64 split markers are supported. supported.

Finally, *Cybercode* [12], Unobtrusive Marker [13], and similar predefined structures have been proposed, along with markers that have an unobtrusive design. However, in order to offer objective identification for large industrial plants and the Internet-of-Things, many more unique, distinguishable IDs are needed.

TABLE II. COMPARISON OF AR MARKER

(+: RELATIVELY GOOD, ~: NORMAL, -: RELATIVELY BAD)

Code type	Design	Occlusion invariant	Decoding	Number of ID
ARTag [10]	-	~	+	2,002
ARToolkit [9]	+	-	-	~100
ARToolkitPlus [11]	+	~	+	512/4,096
Frame marker [14]	+	-	+	512
Split marker [13]	+	~	+	512
Dot marker [13]	+	+	-	512

In order to ensure stable recognition and tracking, the number of recognizable IDs with AR markers is relatively small compared to barcode markers. Therefore, barcode technology was applied to the research described in this paper, in order to overcome this limitation. Furthermore, to mitigate the weaknesses of barcode makers with regard to distortion and scale invariance, recognition technology used in AR markers is applied in order to offer better recognition and tracking technology.

II. PRELIMINARY STUDY

In this paper, to address the insufficient identification volume of conventional AR systems, we integrate barcode-based code technology with marker-based AR technology. To combine these two technologies, it is important to evaluate conventional image-based codes with regard to which one is suitable for marker-based AR. Therefore, we executed an experiment to evaluate image-based code systems. This experiment was aimed at determining the best code to combine with AR technology. Because it is important that AR markers are recognized and augmented continuously, a wide recognition range and a small-sized marker were important.

Therefore, we performed a comparison of three typical barcode-based codes—viz., *QR Code*, *Data Matrix*, and *ColorCode*. For this experiment, we used an iPhone to detect the three codes. We conducted 100 trials for each type of code, and calculated the average.

A. Recognition Distance

We used a 100 mm × 100 mm code to determine the recognizable distance from a variety of angles. In order to use the code in mobile environments, it must be recognizable at a far distance. Experimental results for the recognition distance and angles are provided in Table III.

Table III. RECOGNIZING AREA OF EACH CODES

Recognizing Area	Data Matrix	QR Code	ColorCode
Max. Distance (m)	~ 1.4	~ 1.3	~ 2.0
Max. Angle(°)	~ 56	~ 61	~ 55

The code with the farthest recognition range was *ColorCode*. However, in terms of the recognition angle, *QR Code* was the most tolerant—although, in terms of the angle, the three codes did not exhibit a significant difference.

B. Minimum Size from a Fixed Distance

In addition, we conducted experiments on the minimum size of the recognizable marker at a fixed distance of 50 cm from the code. We conducted a recognition test, while decreasing by 1 mm a 50 mm × 50 mm code of all three types. The results of this experiment are provided in Table IV.

Table IV. MINIMUM SIZE OF IN A FIXED DISTANCE

Distance (50 cm)	Data Matrix	QR Code	ColorCode
Min. Size (mm)	21.0 × 21.0	31.0 × 31.0	15.0 × 15.0

ColorCode could be recognized at half the size of *QR Code*. As described above, *ColorCode* increases the range of data by using color. *Data Matrix* could also be recognized at a smaller size than *QR Code*, owing to the size of the area of the bit used in the Finder Pattern area.

C. Minimum Size from a Variable Distance

Practically, when users recognize markers with mobile devices, they hold their device with their hand at the most appropriate angle and distance for recognizing the code easily. Thus, we experimented under the assumption that the user will hold the device at a comfortable position and angle, and we measured the smallest size of code that could be recognized.

Table V. MINIMUM SIZE OF A FREE DISTANCE

Free Distance	Data Matrix	QR Code	ColorCode
Min. Size (mm)	8.0 × 8.0	11.0 × 11.0	3.0 × 3.0

In the case of *ColorCode*, the minimum size of the code that could be recognized was 3.0 mm × 3.0 mm. By using color, *ColorCode* showed an increase in the cell's integration, and only a very small area was needed, compared to the other codes. The results show that *ColorCode* can contain information that is about, 1/13 of the size of *QR Code*.

Based on these experimental results, we selected *ColorCode* to apply to our marker-based AR system. *ColorCode* can be recognized in a wide range of conditions, and it allows us to use smaller-sized markers [15].

III. COLORCODEAR

ColorCode resulted in difficulties when applied to the AR system, however, owing to its recognition distance and smaller size. Moreover, most 2D bar codes are designed under the assumption that they will be recognized from the front, such that they can only be recognized at a narrow side-angle.

In the AR system, it is difficult to stabilize the marker in consecutive frames. Consequently, variations to the viewing angle and size can result in recognition errors. To overcome this problem, one common marker-recognition technique is quad detection, as illustrated in Figure. 3.

With AR applications, however, quad detection will fail because various distortions are applied. For recognition that is robust to a variety of perspectival distortions, we applied a modified quad-detection technique [19].

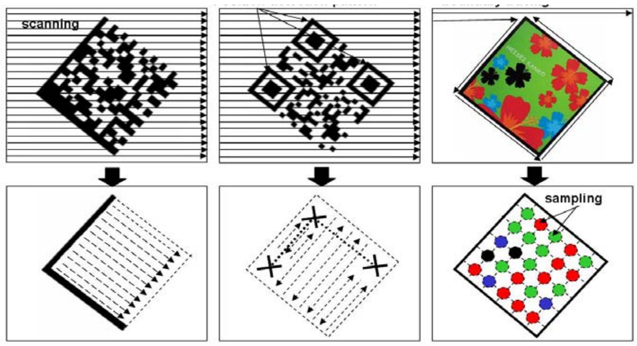

Figure 3. Decoding algorithms of marker. DataMatrix(left); QR code(center); ColorCode(right); Finding code images(top); Decoding(bottom)

In this paper, for reliable recognition with the *ColorCode*-based AR system, we implemented the quad detection and tracking technique at various angles and distances.

Because a common marker-detection technique is used for tracking-by-detection, failures to detect markers and augmentations of the virtual object are impossible. Therefore, with the proposed system, the marker is either detected continuously, or, after it is first detected, it must be tracked.

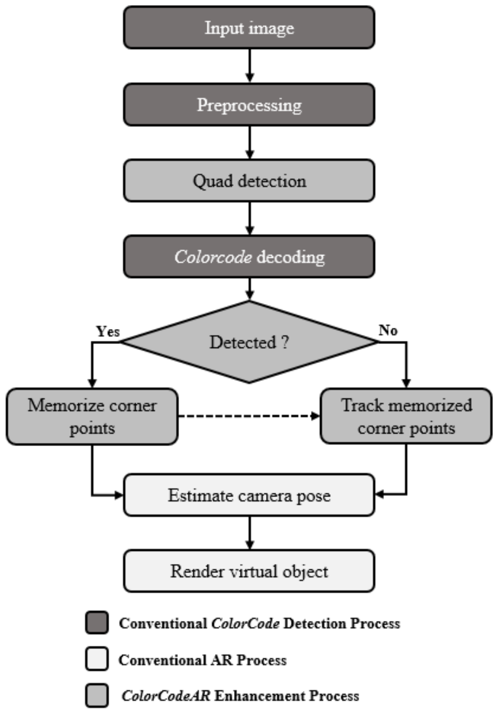

Figure 4. Flowchart of ColorCodeAR. Before to process conventional AR process, the system processes several enhancement processes i.e. quad detection and feature tracking

To resolve these problems, feature-tracking technology is applied. If the proposed system fails to detect a marker, the corner point of the previous frame is traced, and the marker's location is estimated. To do so, we used the Kanade-Lucas-Tomasi (KLT) feature-tracking algorithm.

Figure 4 shows a flowchart of the proposed *ColorCodeAR*. The acquired video undergoes quad detection after preprocessing. However, the recognized area must always be rectangular, in order to perform *ColorCode* decoding [8]. Insofar as it recognizes colors, *ColorCode* is vulnerable to changes in illumination. We solved this problem with the method presented in [16].

When *ColorCode* recognition succeeds, the AR process follows. We added a tracking module to overcome failed marker detections, in order to ensure stable recognition. The traditional AR process is shown in bright gray. The slightly darker gray area denotes the *ColorCode* recognition process, and the darkest gray denotes the improved process—viz., the proposed *ColorCodeAR*.

IV. Experiments

The proposed *ColorCodeAR* is designed to expand the detection range with seamless interaction. Further, *ColorCodeAR* is capable of a large-scale expansion of the identification IDs as a result of using the *ColorCode* technology.

Therefore, *ColorCodeAR* might provide more identification IDs than previous AR systems. Table II compares the number of markers offered by previous AR systems, showing the results of a comparative experiment on the recognition range of AR.

First, to reduce the variable illumination changes, as shown in Figure 5, we used *ColorCode* codes that were 34 mm × 34 mm on an AMOLED display. Using a mobile device (iPhone 5S) at various distances and angles, we compared the recognition rate of the conventional algorithm to that of the proposed algorithm.

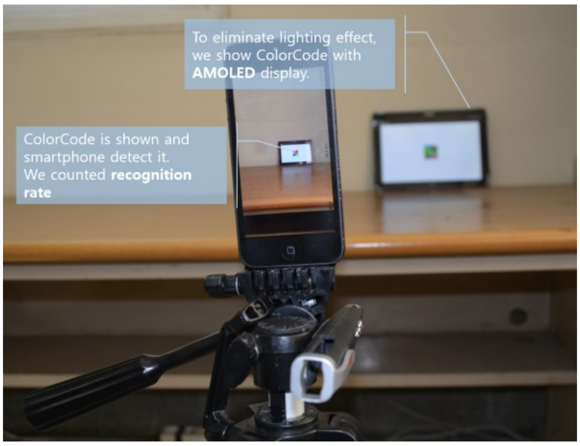

Figure 5. Experiment Environment

According to [18], a 55 mm × 55 mm marker can be recognized at a maximum distance of 70 cm with *ARToolKit* markers. With a typical AR system, the marker can be recognized at approximately 20° to 45° relative to a 90° angle [17]. However, *ColorCode* uses color to increase the degree of cell integration, showing good recognition performance even at greater distances and wider angles.

In the experiment, we started at 2 m and measured the recognition performance at increments of 10 cm up to the maximum distance at which recognition was possible. Moreover, angles were measured from 90° in decrement of 5°.

The recognition performance of the conventional *ColorCode* is detailed in Table VI(a). The recognition performance of *ColorCodeAR* applied to the proposed technology is described in Table VI(b).

The conventional method recognized codes at a distance of up to 1.7 m, and its performance was reliable within 1.5 m. In addition, the recognition angle could range from 55° to 90°, but at 50° the code could not be detected at all, regardless of the distance.

Table VI. EXPERIMENT RESULT

Distance \ Angle(°)	90	85	80	75	70	65	60	55	50	45	40	35	30	25
0.1	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
0.2	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
0.3	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
0.4	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
0.5	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
0.6	100%	100%	100%	100%	100%	100%	100%	90%	0%	0%	0%	0%	0%	0%
0.7	100%	100%	100%	100%	100%	90%	73%	70%	0%	0%	0%	0%	0%	0%
0.8	100%	100%	100%	100%	100%	77%	67%	60%	0%	0%	0%	0%	0%	0%
0.9	100%	100%	100%	100%	97%	60%	27%	0%	0%	0%	0%	0%	0%	0%
1.0	100%	100%	100%	100%	73%	47%	0%	0%	0%	0%	0%	0%	0%	0%
1.1	100%	100%	100%	100%	57%	27%	0%	0%	0%	0%	0%	0%	0%	0%
1.2	100%	100%	100%	83%	37%	7%	0%	0%	0%	0%	0%	0%	0%	0%
1.3	100%	100%	90%	53%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.4	100%	97%	77%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.5	77%	70%	63%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.6	63%	57%	37%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.7	47%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

(a) Recognition rate of conventional *ColorCode*

Distance \ Angle(°)	90	85	80	75	70	65	60	55	50	45	40	35	30	25
0.1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	77%	0%
0.2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	60%	0%
0.3	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	70%	50%	0%
0.4	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	70%	60%	43%	0%
0.5	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	60%	47%	17%	0%
0.6	100%	100%	100%	100%	100%	100%	100%	100%	97%	83%	60%	27%	7%	0%
0.7	100%	100%	100%	100%	100%	100%	100%	80%	70%	60%	33%	27%	0%	0%
0.8	100%	100%	100%	100%	100%	97%	93%	63%	43%	37%	0%	0%	0%	0%
0.9	100%	100%	100%	100%	100%	83%	83%	40%	33%	10%	0%	0%	0%	0%
1.0	100%	100%	100%	100%	100%	87%	77%	30%	0%	0%	0%	0%	0%	0%
1.1	100%	100%	100%	100%	100%	73%	50%	0%	0%	0%	0%	0%	0%	0%
1.2	100%	100%	100%	100%	63%	63%	23%	0%	0%	0%	0%	0%	0%	0%
1.3	100%	100%	100%	100%	37%	30%	0%	0%	0%	0%	0%	0%	0%	0%
1.4	100%	100%	83%	73%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.5	100%	100%	70%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.6	93%	93%	53%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.7	53%	67%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.8	27%	37%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.9	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

(b) Recognition rate of proposed *ColorCodeAR*

On the other hand, the proposed algorithm recognized codes up to 1.8 m away, and exhibited a high recognition rate that was reliable at various angles within 1.6 m. Moreover, the proposed algorithm successfully recognized codes at angles from 30° to 90°. At 25°, however, the codes could not be detected at all, regardless of the distance. The proposed method thus demonstrated performance improvements in terms of the recognition angle. By applying the modified quad-detection algorithm, it was possible to recognize a wider range of codes than with the conventional method.

V. Conclusion

In this research, we developed marker-based AR technology to enhance AR systems. Previous AR marker technology used a black–white structure, such that the ID volume it supported was limited. AR marker technology using previous image-based codes was proposed in this study, in order to overcome these limitations. To apply image-based codes to the AR field, a wide scope of recognition must be offered for continuous interaction. A comparative experiment was conducted with previous code technologies, and the most suitable type—viz., *ColorCode*—was used for an AR system. However, because *ColorCode* assumes one-time recognition, its scope of recognition is limited compared to that of previous AR markers. Therefore, quad-detection technology from a previous marker-based AR system was applied, and feature tracking was used to increase the scope of recognition. In particular, ColorCodeAR uses color information to increase the degree of information integration in each cell. Consequently, it can use markers in the form pictorial image codes. Thus, it solves the problem of obtrusiveness, a weakness in previous AR markers.

Recently, research into markerless-based AR, rather than marker-based AR, has been actively promoted. However, these two approaches differ in terms of their respective applications. Marker-based AR conduces to ID commerce, ticketing, and industrial plants, whereas markerless-based AR is mainly applied to User Experience designs—e.g., in games, medicine, and education. Nonetheless, because the proposed ColorcodeAR can be adopted by a variety of designs involving color, it can also be adopted by both marker-based AR and markerless-based AR. As such, it can be applied to a wide range of fields.

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