Spatially-Multiplexed MIMO Markers

Hideaki Uchiyama*
Kyushu University

Shinichiro Haruyama†
Keio University

Atsushi Shimada‡
Kyushu University

Hajime Nagahara§
Kyushu University

Rin-ichiro Taniguchi¶
Kyushu University

Abstract

We present spatially-multiplexed fiducial markers with the framework of code division multiple access (CDMA), which is a technique in the field of communications. Since CDMA based multiplexing is robust to signal noise and interference, multiplexed markers can be demultiplexed under several image noises and transformation. With this framework, we explore the paradigm of multiple-input and multiple-output (MIMO) for fiducial markers so that the data capacity of markers can be improved and different users can receive different data from a multiplexed marker.

Index Terms: H.5.1 [Information Interfaces and Presentation (e.g., HCI)]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities; I.4.8 [Image Processing and Computer Vision]: Scene Analysis—Tracking

1 Introduction

A fiducial marker, which is typically designed with geometric primitive shapes and simple combinations of colors, has been utilized for developing 3D user interfaces. The design of a fiducial marker has been studied for over a decade. ARToolKit developed by Kato and Billingusrt is the most famous and commonly used in AR systems [2]. ARTag is also a well-known tool that uses a sophisticated signal processing theory for designing and recognizing binary patterns [1]. Uchiyama and Saito proposed to use the collection of randomly distributed dots so that the marker is no longer limited to square structure and it can be detected and recognized under large occlusion [3]. While a fiducial marker with natural texture is becoming popular, new design and functionality of a fiducial marker have still been investigated as well.

In order to enhance the functionality of fiducial markers, we propose to incorporate the paradigm of MIMO, which is generally used in the field of communications. MIMO means multiple antennas at both the transmitter and receiver are utilized for improving communication performance. For fiducial markers, we consider that multiple antennas at the transmitter correspond to multiple markers and those at the receiver are multiple cameras. This means that different users can receive different data from a multiplexed marker. To develop MIMO markers, we use CDMA [4], which is a multiplexing technique in wireless communications. Since CDMA based communications are well-known as robust to noise and interference because of a spread spectrum based approach, we validate such advantages through our experiments.

*e-mail: uchiyama@limu.ait.kyushu-u.ac.jp
†e-mail: haruyama@sdm.keio.ac.jp
‡e-mail: atsushi@limu.ait.kyushu-u.ac.jp
§e-mail: nagahara@limu.ait.kyushu-u.ac.jp
¶e-mail: rin@kyudai.jp

2 Design of Multiplexed Markers

Since CDMA in wireless communications deals with a one-dimensional signal, we extend CDMA to two-dimensional signals as follows.

First, multiple binary data for transmission are prepared and each data is arranged in a 2D matrix like an image array. For example, three 16-bit binary data are illustrated in Figure 1. Next, spreading codes orthogonal to each other are prepared and multiplied with each data to generate encoded data. Finally, the encoded data are summed up and normalized into the range of image intensity. Note that data for transmission, spreading codes and encoded data are described in the signal space and their images in Figure 1 are generated only for visualization.

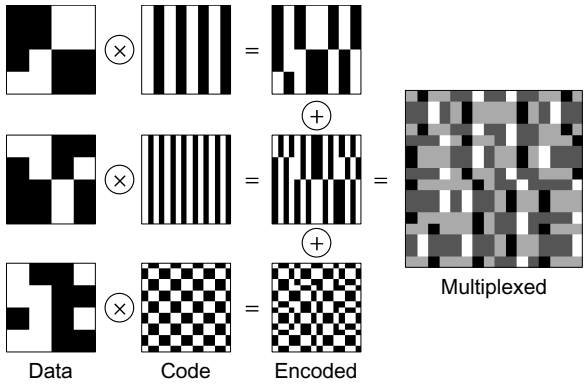


Figure 1: Design of multiplexed markers. Multiple 2D binary data are multiplexed with CDMA. Multiplexed data in the signal space are then normalized into the range of image intensity.

3 Decoding with a camera

The decoding process of multiplexed markers is the same as CDMA in wireless communications as follows. To receive data, users capture the marker with a camera as illustrated in Figure 2. From the captured image, square regions are detected and rectified onto a canonical view, which size is equal to that of the marker. Then, each spreading code is multiplied with the rectified images and each transmitted data can finally be decoded. Since the decoded data may include some noise and are not binary, they are finally binarized to get binary data. Note that we use a black frame to simplify marker detection as done in typical square markers [2, 1].

4 Evaluation

To validate some advantages of CDMA, we show the decoding results with captured images. As illustrated in Figure 3, we captured the multiplexed marker illustrated in Figure 1 and Figure 2 from various angles and distance. Thanks to a black frame around the marker, the marker was stably detected for all the images. From Figure 3, it is obvious that decoded data can be correctly binarized by a discriminant analysis.

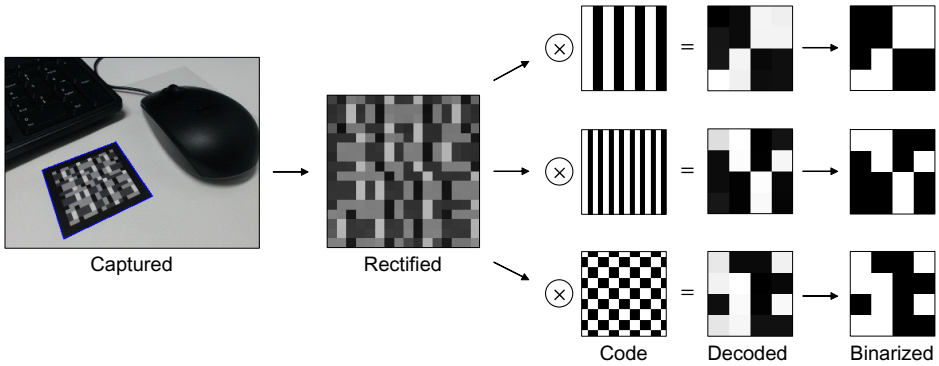


Figure 2: Decoding multiplexed markers with a camera. A multiplexed marker is captured with a camera. From the captured image, square regions are detected and rectified onto a canonical view. Each rectified image is then multiplied by each spreading code so that the transmitted data is recovered.

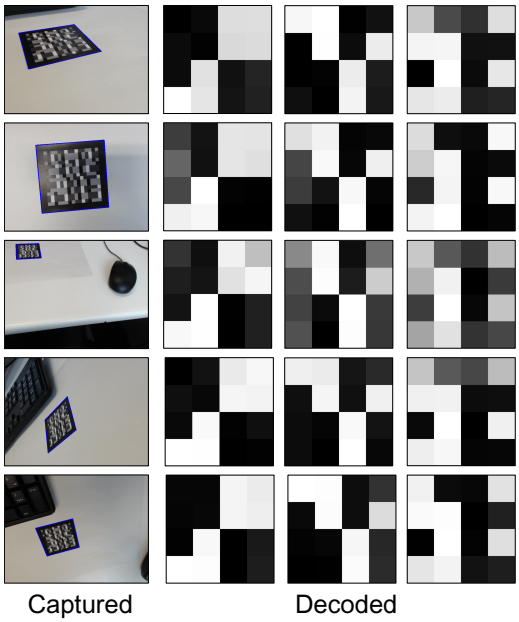
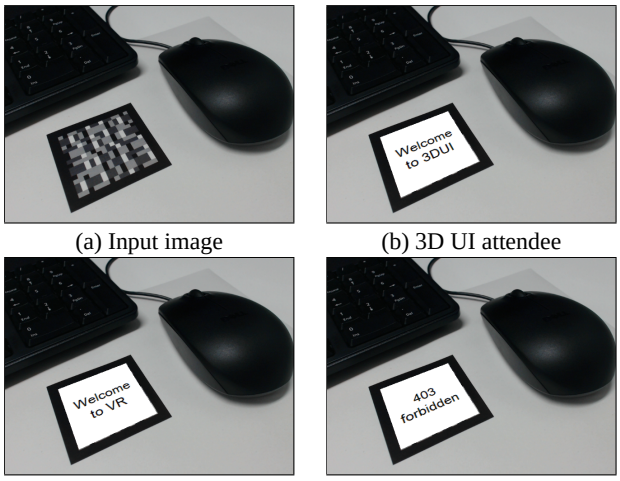


Figure 3: Evaluation with real images. The marker used was illustrated in Figure 1 and Figure 2. The marker was stably detected even when it was captured from string perspective views thanks to a black frame. The decoded raw data are visualized to validate the results.



(a) Input image (b) 3D UI attendee

(c) VR attendee (d) With a wrong code

Figure 4: Application of information presentation. For an input image (a), the content can be switched as (b) and (c) depending on a spreading code. We can notice that the code is wrong as (d).

5 Application

We introduce an example of the use of a MIMO marker. The main functionality of a MIMO marker is that the marker can provide different data depending on a code offline. For example, the software for decoding the marker is provided for all the attendees in a conference and the different codes are distributed depending on the user's property such as the difference of the registration as illustrated in Figure 4. We can also notice that the marker is being attacked if it is decoded with an incorrect code.

6 Conclusion

We presented spatially-multiplexed multiple binary patterns with the framework of CDMA. Thanks to the property of CDMA, the multiplexed marker can be decoded under image noises. From the evaluation, we confirmed that our markers can be stably recognized even under several image noises and transformation.

The multiplexed marker has a property that the code used in multiplexing data is necessary for decoding the data. This enables the development of some applications such that users only who have the code can decode the data. In the future, a method for detecting a multiplexed marker without a black frame would be investigated.

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